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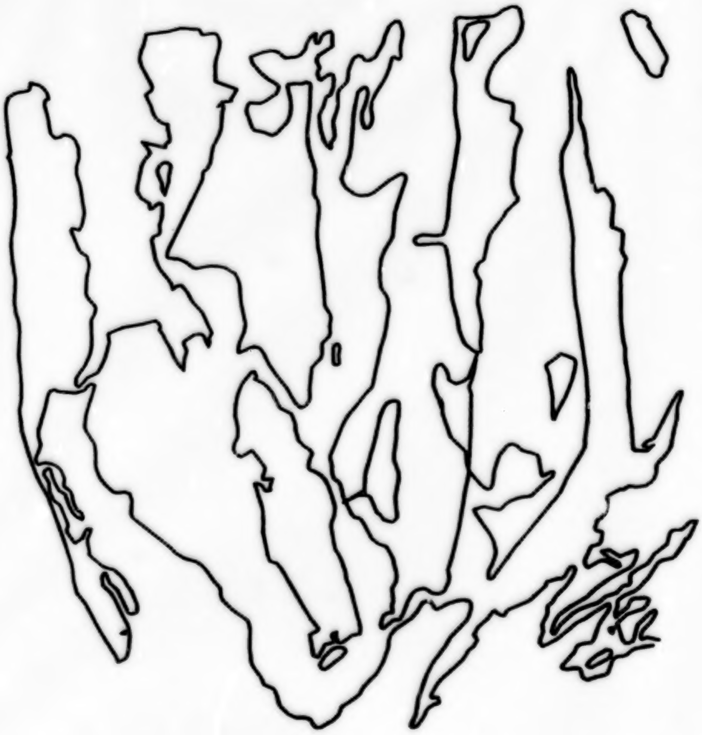
Hydrologic Modification for Habitat Improvement in the Finger Lakes:

Pre-Project Report Number 3, 1994



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Hydrologic Modification for Habitat Improvement in the Finger Lakes: Pre-Project Report Number 3, 1994

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The Environmental Management Technical Center issues LTRMP Technical Reports to provide Long Term Resource Monitoring Program partners with scientific and technical support.

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Preface

The Long Term Resource Monitoring Program (LTRMP) was authorized under the Water Resources Development Act of 1986 (Public Law 99-662) as an element of the U.S. Army Corps of Engineers' Environmental Management Program. The LTRMP is being implemented by the Environmental Management Technical Center, an office of the National Biological Survey, in cooperation with the five Upper Mississippi River System states, Illinois, Iowa, Minnesota, Missouri, and Wisconsin, with guidance and Program responsibility provided by the U.S. Army Corps of Engineers.

The mission of the LTRMP is to provide decision makers with information to maintain the Upper Mississippi River System as a viable large river ecosystem given its multiple-use character. The long-term goals of the Program are to understand the system, determine resource trends and impacts, develop management alternatives, manage information, and develop useful products.

This report was prepared under Strategy 3.3.2, *Test and Assess the Effectiveness of Prototype Management,* as specified in Goal 3 of the Operating Plan of the LTRMP for the Upper Mississippi River System (USFWS 1992). The purpose of this report is to summarize findings obtained during 1993, the third year of the Finger Lakes study effort.

This report was developed with funding provided by the Long Term Resource Monitoring Program. The investigations upon which this report is based were partially supported by the Corps of Engineers, St. Paul District, and the LTRMP.

Additional copies of this report may be obtained from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

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Introduction

The Upper Mississippi River System (UMRS) has long been recognized as a unique national resource. In the Water Resources Development Act of 1986 (Public Law 99-662), the U.S. Army Corps of Engineers (Corps) was given responsibility to ensure the development and enhancement of the UMRS. The National Biological Survey (NBS) and several states are participating as partners with the Corps in the resultant Corps-sponsored Environmental Management Program (EMP). One of several major thrusts within the EMP involves habitat rehabilitation. The Environmental Management Technical Center (EMTC) of the NBS, located in Onalaska, Wisconsin, has been requested by the Corps to provide technical assistance in planning and conducting ecological monitoring efforts in conjunction with various Habitat Rehabilitation and Enhancement Projects (HREPs).

Currently, personnel from the EMTC, the National Fisheries Research Center (NFLX) of the NBS, and the Corps (Waterways Experiment Station, Eau Galle Limnological Laboratory) are engaged in investigations on the Finger Lakes complex. This complex consists of six connected lakes located in Navigation Pool 5 just downstream from the dike at Lock and Dam 4, near Kellogg, Minnesota. During the winter, several of these lakes experience low oxygen concentrations and extreme water temperatures, conditions that substantially reduce their suitability for fish. To improve fish habitat, the Corps, St. Paul District, in 1994 retrofitted an existing culvert system and installed additional controlled-flow culverts to regulate the hydrology of the lake complex. During the period 1991-1993, preconstruction monitoring data were obtained by the agencies specified above to evaluate project success.

The Finger Lakes investigation is designed to examine experimentally the effects of management measures directed toward fisheries improvements, with adequate attention also to effects on a wide variety of other important and interrelated variables. Ongoing studies focus on changes in hydrology, water quality, sedimentation, vegetation, fish, and invertebrates affected by hydrologic modification. A major goal of the Finger Lakes HREP is to improve winter habitat conditions for fish. Associated efforts are aimed at quantifying spatial-temporal patterns and interrelationships among water movement, oxygen, sediment type, vegetation, macroinvertebrates, and temperature.

The studies described herein were initiated in 1991 and are anticipated to span a 5-year period. The purpose of this report is to summarize findings obtained during 1993, the third year of the Finger Lakes study effort. This report is the third in a series which addresses pre-project conditions.

Hydrology and Sedimentation

Dye Studies

Dye studies were conducted in the Finger Lakes during the week of February 1, 1993. At the culvert in Lower Peterson Lake, a fluorescent dye, rhodamine WT, was injected to determine the time-of-travel and the dispersion of the dye cloud as it passed through the Finger Lakes system. Time-of-travel stations were established using automated fluorometers at the lower end of Lower Peterson Lake (TT-1), the lower end of Schmoker's Lake (TT-2), and the outflow (TT-3) from the Finger Lakes system (Fig. 1).

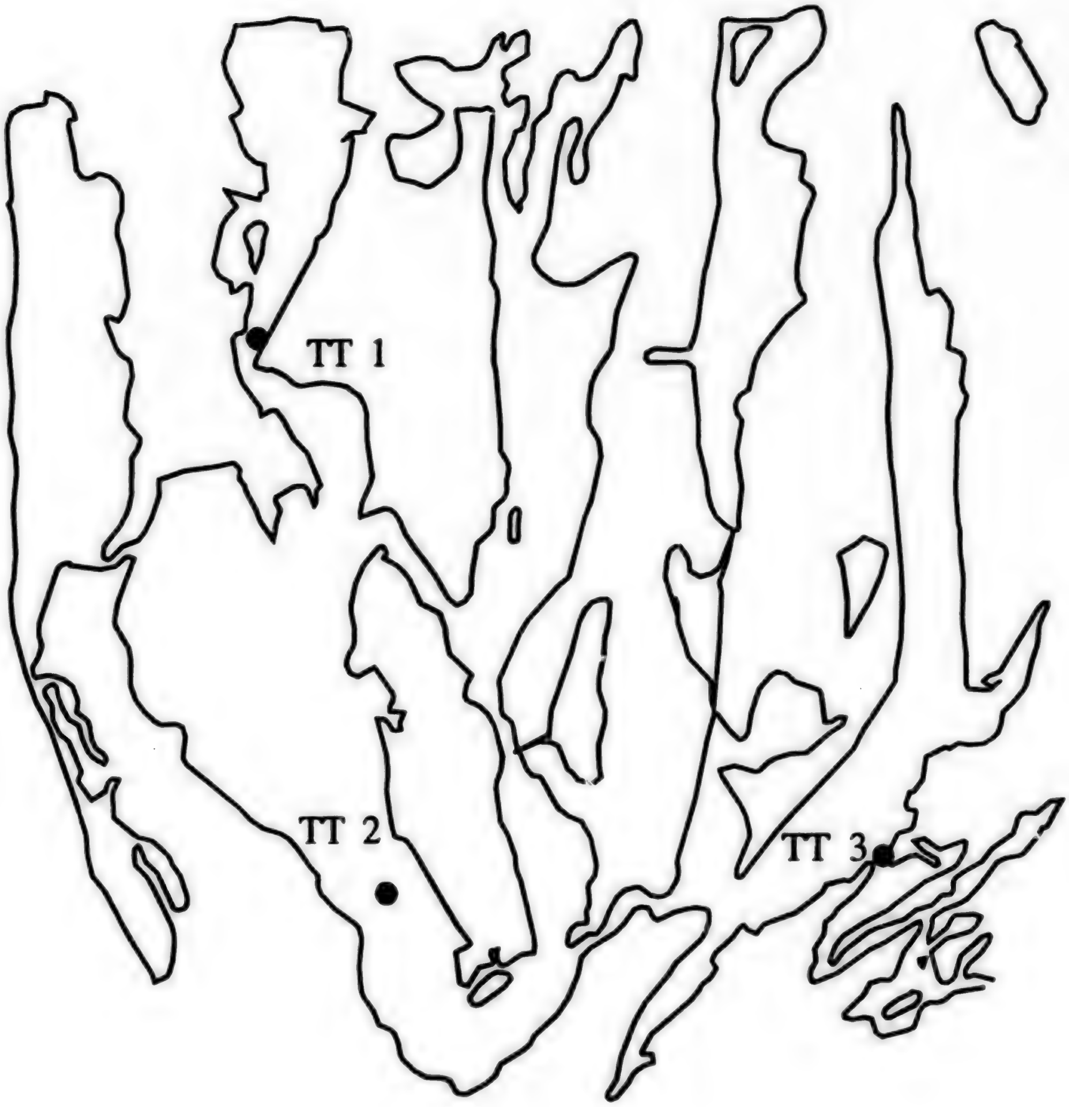

Figure 1. Map of the Finger Lakes showing the time-of-travel stations (TT-1, TT-2, and TT-3) and lateral dispersion transects in Schmoker's Lake for the 1993 dye study. Also shown are the dye injection locations (CL and TH) for the ancillary dye studies conducted in Clear and Third Lakes.

In 1993, time-of-travel, or the time required for the peak concentration of the dye cloud to reach the monitoring station, was very similar to the time observed in 1992 (Fig. 2). Travel time to TT-1 was slightly faster (approximately 0.5 h) in 1993 than in 1992. At the lower end of Schmoker's Lake, the dye reached TT-2 about 1 h later than in 1992. Dye concentrations peaked in the outlet (TT-3) about 1 h earlier in 1993 than in 1992. Given the similarity in timing and the shapes of these curves, differences between years are probably insignificant. Travel times and average current velocities were very similar in 1992 and 1993.

Secondary dye studies were conducted in Clear and Third Lakes in an attempt to determine the significance of groundwater inputs to the hydrology of these lakes. Dye was injected at the locations marked as CL and TH on Figure 1. These ancillary studies did not result in a great deal of data, but they did provide some qualitative hydrologic information. In Clear Lake, movement of the dye cloud was very slow and, in 24 h, had expanded only 2.5 m from the point of injection. Movement was to the east and south, toward the outflow from Clear Lake into Schmoker's Lake. In Third Lake, movement of the dye cloud was much faster than expected. In 24 h, the trailing edge of the dye cloud was approximately 60 m to the south of the injection point. At this time, the leading edge of the cloud may have already passed the point where the outlet channel from Third Lake joins with the outlet channel from Schmoker's Lake. The rapid water movement observed in Third Lake may be the result of one of the following: (1) input from springs (i.e., groundwater) in Third Lake or (2) entrainment by water moving through the channel at the lower end of Third Lake.

Tailwater Elevations

Water elevations in the tailwaters of Lock and Dam 4 and, therefore, elevations in the Finger Lakes (Barko et al. 1993) were extremely high from April through September 1993 (Fig. 3). During the period from mid-June to mid-September, elevations were much higher than the 90th percentile of a 50-year record of elevations. This high water event reestablished the Mississippi River's connection to these lakes for most of the spring and summer. The impacts of this event are discussed below.

Due to the high water conditions during the open water season, it was impossible to gage either the culvert in Lower Peterson Lake or the outflow from the Finger Lakes complex. The culvert could not be gaged because it was under water for most of April through September 1993. High water inundated the discrete outlet channel and, as a result, outflow from the Finger Lakes was not held to a measurable channel.

Annual water levels for Dam 4 tailwaters have revealed different hydrographs for each year (1991-1993). Peak water levels occurred in May and June in 1991, in March and April in 1992, and in June and July in 1993. Mean growing season water levels in 1993 were significantly higher (665.2 ft; $P < 0.05$) than in 1992 (661.6 ft) and in 1991 (662.8 ft). The greatest frequency of high water levels (daily water levels exceeding the 3-year growing season mean of 663.2 ft) occurred in 1993, when water levels exceeded 663.2 ft for 159 days. The lowest frequency of high water levels occurred during 1992 (21 days).

Calculation of Culvert Flow Rates for Project Operation

Construction of the new gated culverts was completed in late November 1993. Before the initiation of a new hydrologic regime for the Finger Lakes, personnel from the EMTC, NFLX, and the U.S. Fish and Wildlife Service met to determine the initial flow rates for the gated culverts. At that

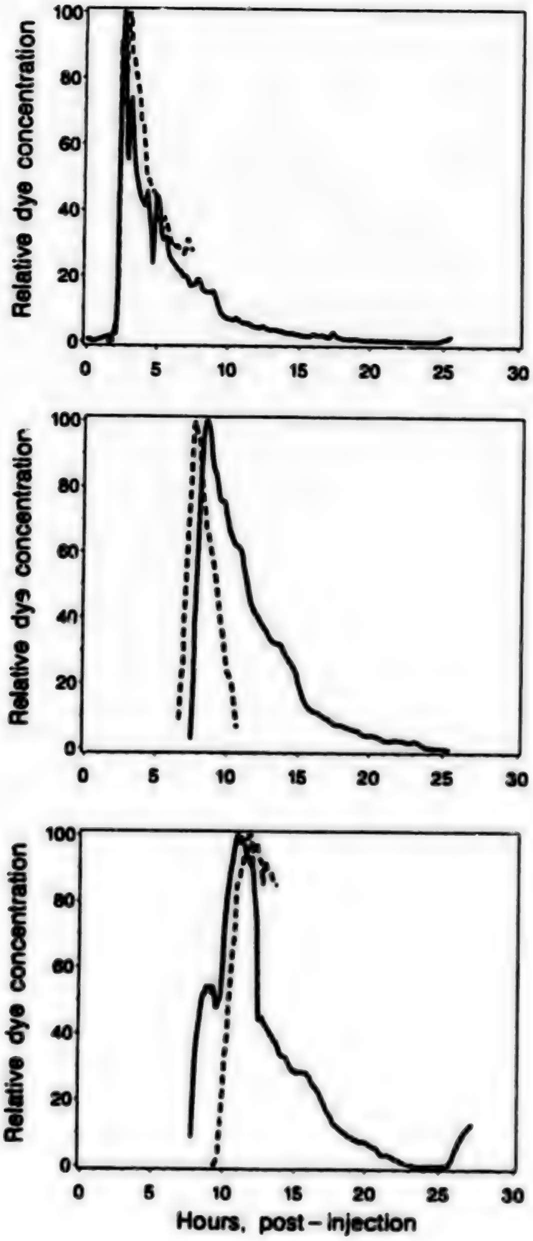

Figure 2. Relative dye concentration observed at TT-1 in Lower Peterson Lake (top), TT-2 in Schmoker's Lake (middle), and at TT-3 at the outlet (bottom) for 1993 (solid line) and 1992 (dashed line).

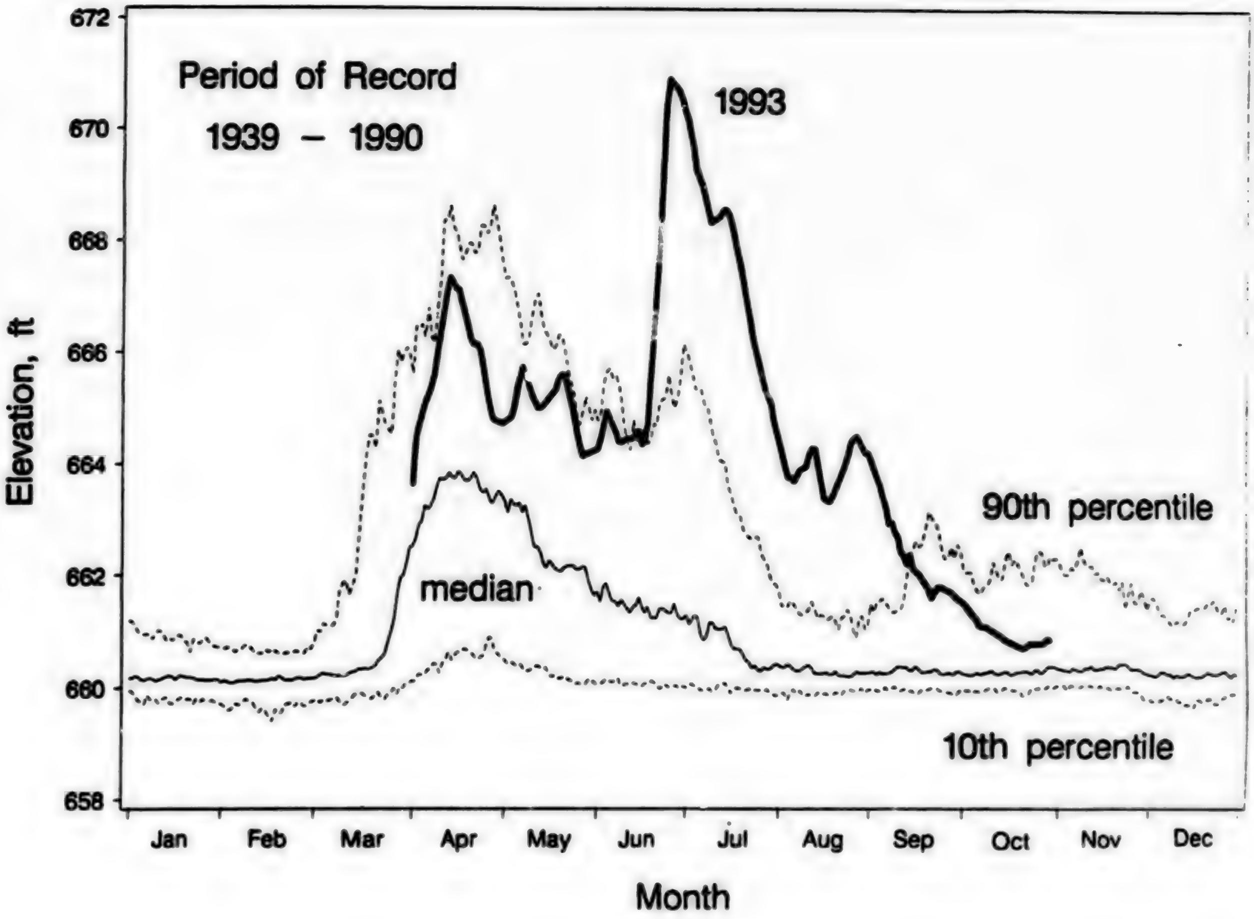

Figure 3. Lock and Dam 4 tailwater elevations, April-October 1993 (thick line), and percentile data for a 50-year record of elevations showing the 10th (lower dashed line), 50th (thin solid line), and the 90th (upper dashed line) percentiles.

meeting, it was decided to use Third Lake as a control and keep it isolated from the river (i.e., the culvert would not be operated). Initial flow rates were calculated based on the following premises regarding winter conditions:

a. dissolved oxygen in the outflow from the culverts would be 10 mg/L,
b. oxygen consumption rate in the lakes would be 0.5 mg/L/day, and
c. a minimum acceptable dissolved oxygen concentration would be 3 mg/L.

These premises were founded on observed winter dissolved oxygen levels in Peterson Lake, oxygen consumption rates in the Finger Lakes, and a conservative estimate of the oxygen requirements of bluegills and black crappies.

Implicit in the above premises is the idea that providing just enough oxygen to stay above the minimum acceptable level would keep current velocities in the lakes to a minimum. The calculation also relied on the lake volumes given in Table 1.

Table 1. **Lake volumes (m^3) for the Finger Lakes**

Lake	Volume (m^3)
Clear	84,300
Lower Peterson	94,000
Schmoker's	163,700
First	56,000
Second	18,000

Given the above premises, 7 mg/L (10-3 mg/L) would be available for consumption while a given parcel of water moved through the lake. Knowing the amount of oxygen available and the oxygen consumption rate, the maximum system residence time was calculated. With 7 mg/L available for consumption and a consumption rate of 0.5 mg/L/day, maximum system residence time is 14 days ([7 mg/L]/[0.5 mg/L/day]).

Given that both Clear and Lower Peterson Lakes flow into Schmoker's Lake, these three lakes had to be considered as a system for the hydrologic computations. In other words, the calculations had to address the need for providing sufficient oxygen through Schmoker's Lake from Clear and Lower Peterson Lakes, because Schmoker's Lake does not receive direct inputs. First and Second Lakes were assumed to be independent systems because both lakes receive direct inputs. Culvert flow rates (m^3/s) were calculated by dividing the system volumes by the maximum system residence time (Table 2). The total inflow rate of 0.28 m^3/s into the complex of Clear, Lower Peterson, and Schmoker's Lakes was partitioned based on volume. The culvert into Clear Lake and the culvert into Lower Peterson Lake each supply one-half of the total flow rate.

With the available morphometric data for the Finger Lakes and the culvert flow rates, estimates of the resultant flow velocities were calculated. Dividing the culvert flow rate by the average cross-sectional area of the lake provides an estimated velocity. This assumes uniform flow through the average cross-section. The average cross-sectional area was calculated by multiplying

Table 2. Culvert flow rates calculated from system volume and maximum residence time

System	Volume (m^3)	Culvert flow rate (m^3/s)	(ft^3/s)
Lower Peterson, Clear, and Schmoker's Lakes	342,000	0.28	10
First Lake	56,000	0.05	2
Second Lake	18,000	0.02	1

the average width by the mean depth. Table 3 lists the estimates of current velocities. These velocities are all well below 1 cm/s, considered the upper bound of optimal flow velocities for bluegills and black crappies (Barko et al. 1993). Flow velocities can also be estimated for Lower Peterson and Schmoker's Lakes under pre-project conditions using the same assumptions and the pre-project flow rate of 2.27 m^3/s through the ungated culvert in Lower Peterson Lake. Pre-project estimated velocities are 1.21 and 1.25 cm/s in Lower Peterson and Schmoker's Lakes, respectively. Flow rates are estimated to drop to 10% or less of the pre-project velocities when the gated culverts are operated.

Table 3. Average velocities resulting from culvert flow rates, assuming uniform flow through the average cross-section

Lake	Culvert flow rate (m^3/s)	Cross-sectional area (m^2)	Velocity (cm/s)
Clear	0.14	121	0.12
Lower Peterson	0.14	187	0.07
Schmoker's	0.28	181	0.15
First	0.05	46	0.11
Second	0.02	53	0.04

Sediment Dynamics

The hydrologic modification of the Finger Lakes will act to restore the connection between these lakes and the Mississippi River. Most of the lakes (First, Second, Third, and Clear) have been isolated from the river, except during periods of high tailwater elevations, since construction of the dike associated with Lock and Dam 4. Significant changes in the quantity and quality of suspended particulate matter are expected to accompany the reintroduction of river inputs to these lakes. To identify these changes, a study was initiated in May 1993 to capture an open water season of pre-project sedimentation data.

Triplicate sediment traps (aspect ratio of 5:1) were placed in each of the Finger Lakes (Fig. 4). Traps were to be retrieved, sampled, and redeployed at 2-week intervals, but high water conditions in late June and July prevented multiple deployments during that period. Dry weight and ash-free dry weight were determined from the sediment trap samples. Gross sedimentation rates ($g/m^2/day$) for particulate matter and organic matter were calculated from these data.

Combining the data from all of the sediment traps across lakes by the deployment period provides a general view of the temporal changes in gross sedimentation in these lakes (Fig. 5). The impact of the 1993 flood is evident in peaks in the rate of particulate and organic matter sedimentation. Peak dry weight accompanied very low values for percent organic matter in the settling material. Water elevations in these lakes were very high from mid-June to early August, and the lakes were connected to the main channel of the Mississippi River. As elevations lowered toward the end of July, the percentage of organic matter in sedimenting particulate matter returned to relatively high levels. This increase in organic matter was associated with increased water clarity in the lakes as they became less affected by the Mississippi River. In turn, increased water clarity supported increased phytoplankton production that presumably lead to an increased percentage of organic matter in the sedimenting material.

Although the combined sediment trap data exhibited a pattern dominated by the influence of the Mississippi River, not all of the lakes responded in the same manner. While most of the lakes do show a temporal pattern influenced by the Mississippi River, in Clear Lake, the gross sedimentation rate did not increase during the flood (Fig. 6). Clear Lake is the most isolated of the Finger Lakes due to its position on the far western side of the complex. Although Clear Lake experienced very high lake elevations during the flood, the data suggest that much of the suspended particulate matter had settled out before reaching this particular lake. This supposition is borne out by gross sedimentation rates during the flood for First, Second, and Third Lakes. Distance from the river increases from First Lake to Third Lake and, with distance, the gross sedimentation rate decreases from First Lake to Third Lake. In Lower Peterson and Schmoker's Lakes, sedimentation rates during the flood were relatively high because these lakes are connected to the river by the culvert in Lower Peterson.

Only Clear and First Lakes exhibited any significant differences in gross sedimentation of organic matter with respect to deployment period (Fig. 7). These two lakes appear to be at opposite ends of the spectrum with respect to flood effects. First Lake exhibited a dramatic increase in the gross sedimentation of organic matter during the flood. However, the deployment periods before and after the peak flood elevations show much lower sedimentation rates. In Clear Lake, on the other hand, organic matter sedimentation was very low during the flood compared with during post-flood conditions. The flood's impact on the light regime in Clear Lake apparently depressed organic matter sedimentation. Given that much of the suspended particulate matter was lost before reaching Clear Lake (see above), only very fine material was left in suspension. This material may have reduced light penetration, thereby decreasing phytoplankton production.

These observations on the changes caused by the 1993 flood may foreshadow the changes caused by the hydrologic modification of the Finger Lakes. While the restoration of flows to these lakes will be much less severe than what occurred with the 1993 flood, the changes that result in these lakes may be very similar. Rates of gross sedimentation will likely increase, with an associated reduction in the proportion of organic matter in the settling material as most of these lakes are shifted from a lacustrine state to a more riverine state. Lower Peterson and Schmoker's

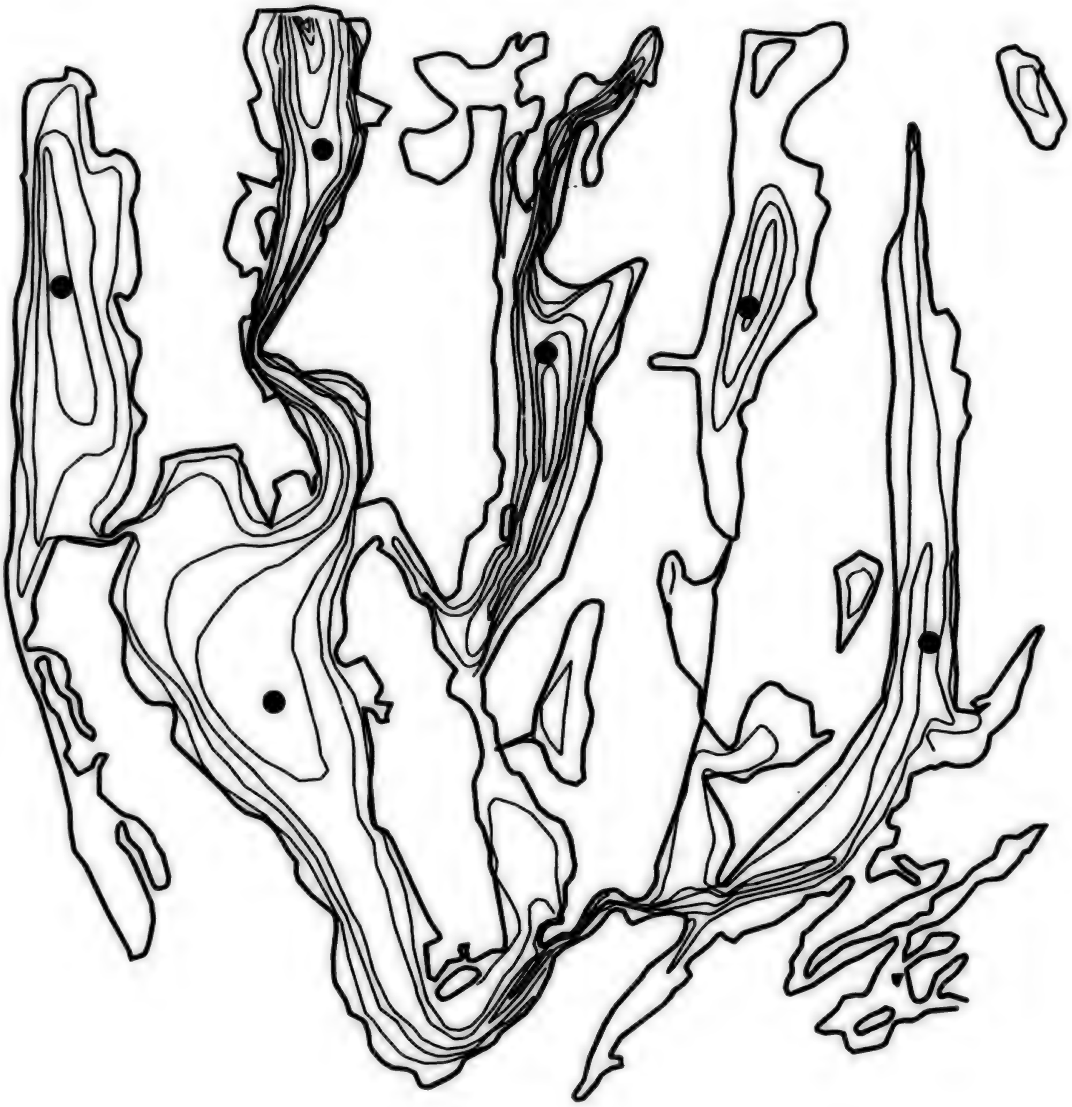

Figure 4. Bathymetric map of the Finger Lakes showing sediment trap locations

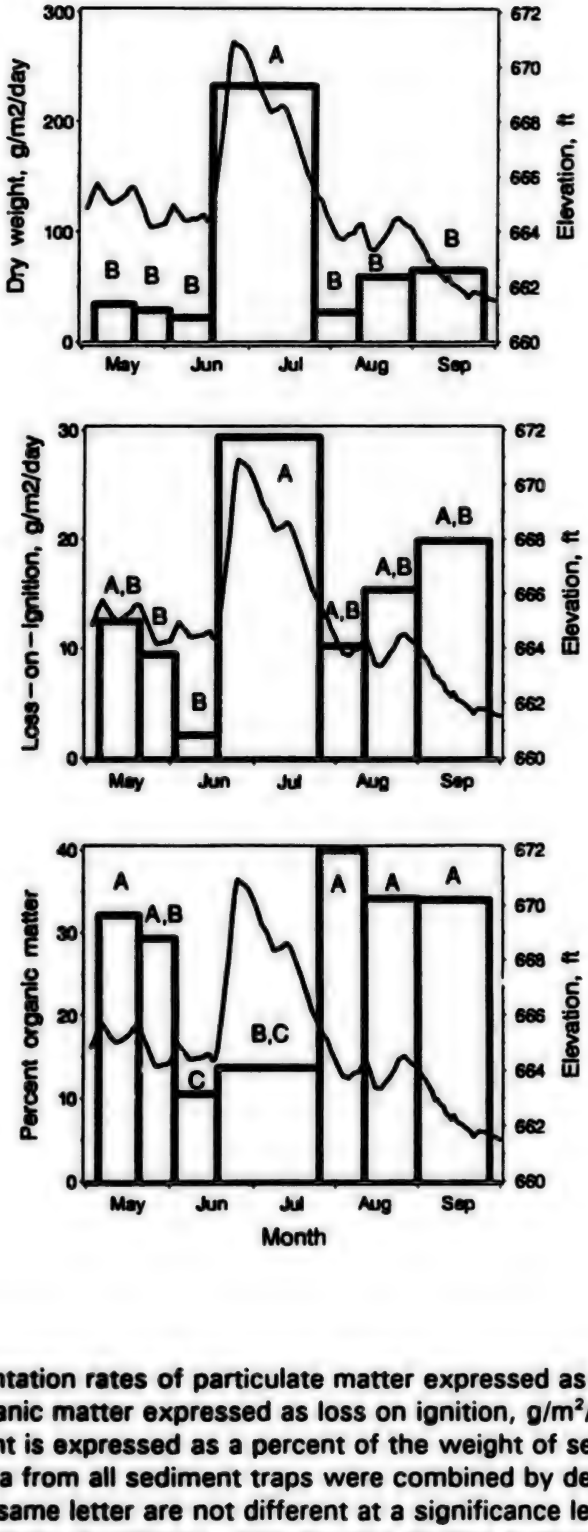

Figure 5. Gross sedimentation rates of particulate matter expressed as dry weight, g/m^2/day (top), and organic matter expressed as loss on ignition, g/m^2/day (middle). The organic content is expressed as a percent of the weight of settling particulate matter (bottom). Data from all sediment traps were combined by deployment period. Vertical bars with the same letter are not different at a significance level of $P = 0.05$ based on a one-way analysis of variance. Line drawing depicts hydrograph.

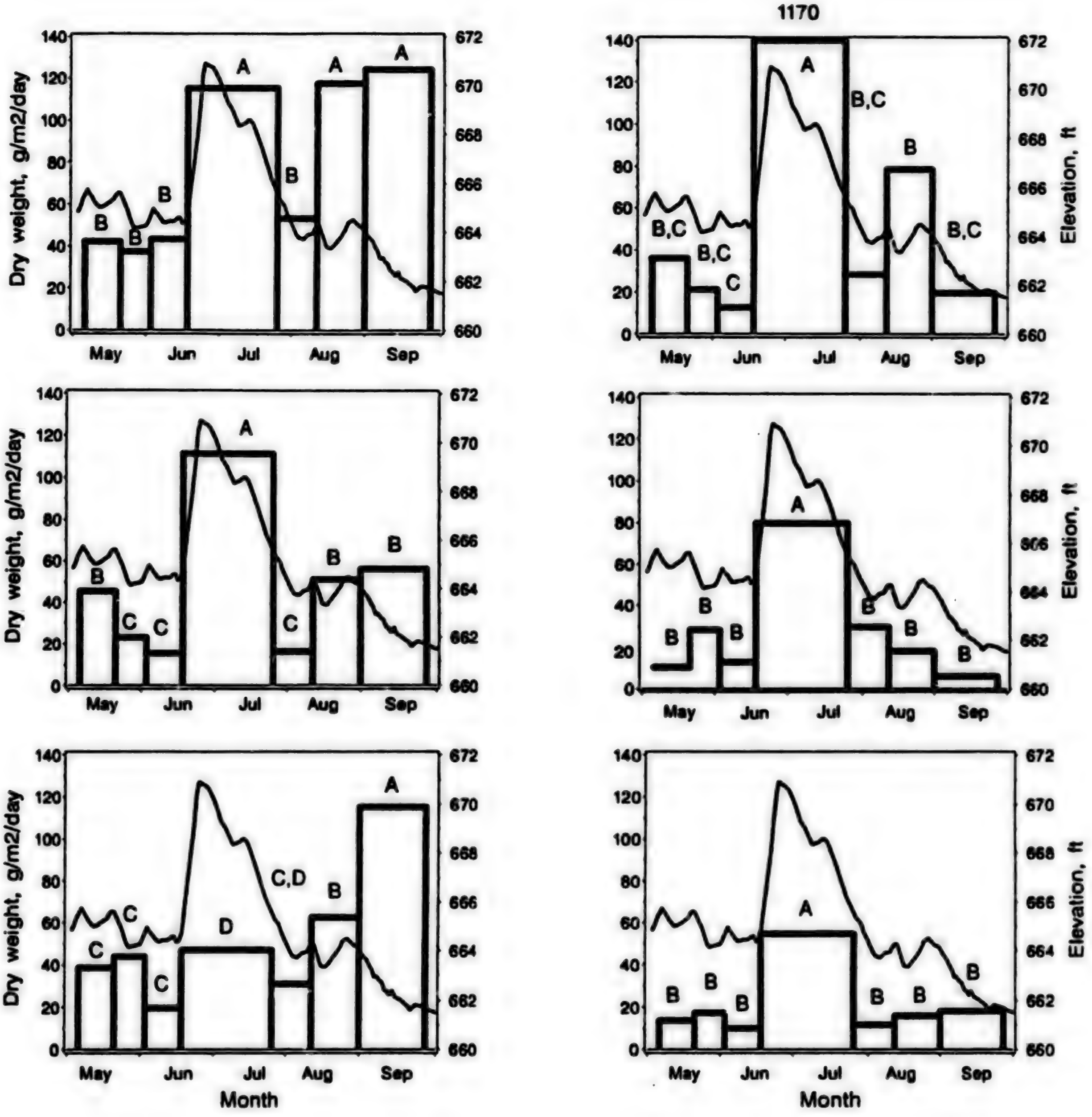

Figure 6. Gross sedimentation rate of particulate matter (dry weight, $g/m^2/day$) for Lower Peterson (top left), Schmoker's (middle left), Clear (bottom left), First (top right), Second (middle right), and Third (bottom right) Lakes. Vertical bars with the same letter are not different at a significance level of $P = 0.05$ based on a one-way analysis of variance. Line drawing depicts hydrograph.

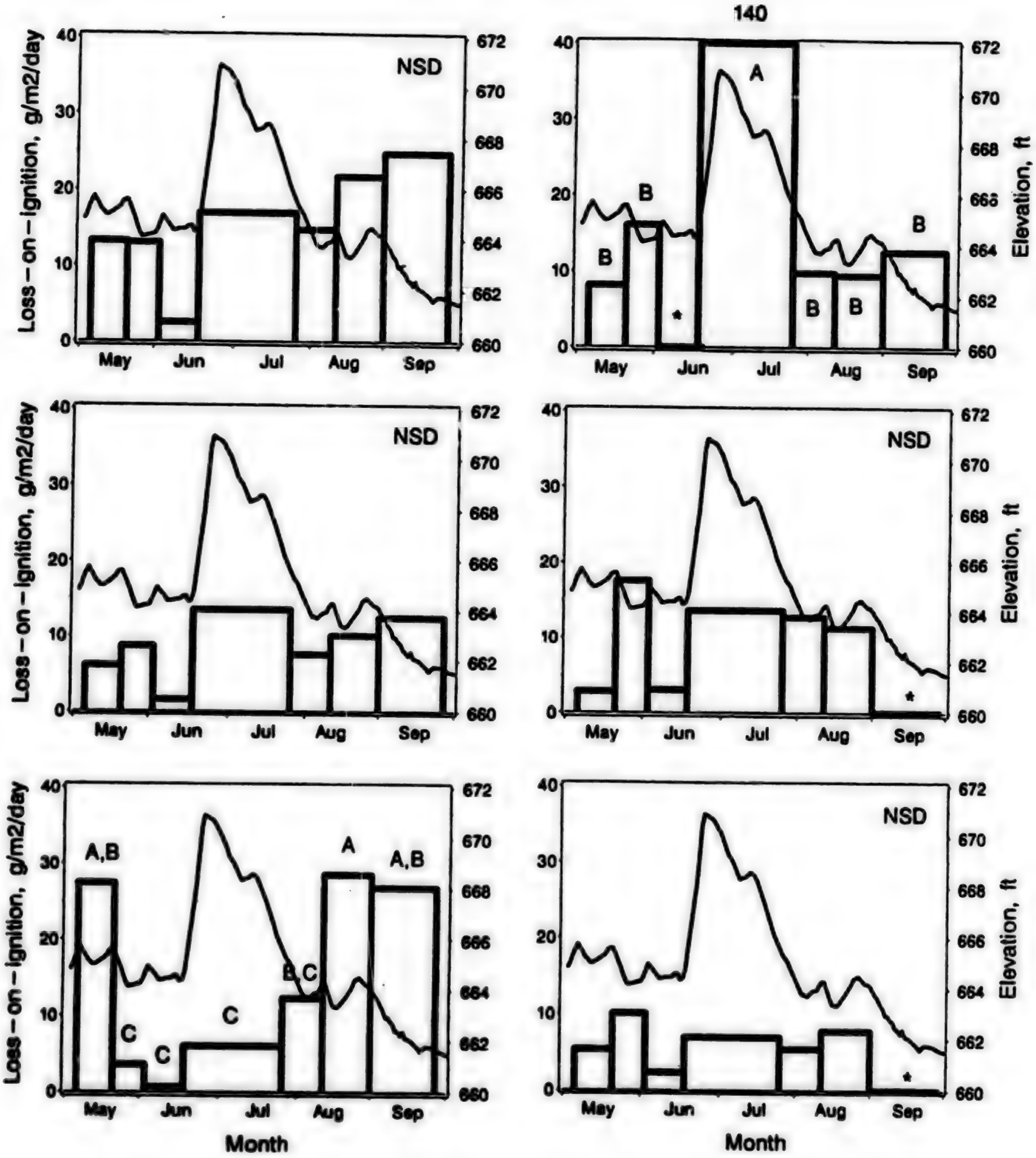

Figure 7. Gross sedimentation rate of organic matter (loss on ignition, g/m²/day) for Lower Peterson (top left), Schmoker's (middle left), Clear (bottom left), First (top right), Second (middle right), and Third (bottom right) Lakes. Vertical bars with the same letter are not different at a significance level of $P = 0.05$ based on a one-way analysis of variance. Line drawing depicts hydrograph.

Lakes may move in the opposite direction, given that the total flow into these two lakes will be reduced considerably.

Synopsis

Dye-tracer studies conducted in 1993 confirmed observations made in 1992 on the water movements in the system. Analyses of these data have provided estimates of the system's hydraulic characteristics. Time-of-travel measurements and estimates of current velocities are generally in agreement with predictions based on system morphometry and input conditions. Post-project flow rates for the gated culverts were calculated and the resultant flow velocities are estimated to drop to 10% or less of the pre-project velocities. A sedimentation study was initiated to document the expected changes in the quantity and quality of suspended particulate matter in the lakes. The impact of the 1993 flood is clearly evident in the data and may foreshadow changes caused by the hydrologic modification of the Finger Lakes.

Water Quality

Water samples and *in situ* measurements were taken at weekly to biweekly intervals between August 1992 and August 1993 at the inflow and outflow of the chain of lakes and at two stations in each lake. During ice-covered periods, measurements were collected less frequently. Mid-depth water samples were collected at each lake station with a peristaltic pump and were analyzed for alkalinity, suspended seston, particulate organic matter, dissolved organic carbon, total nitrogen, total soluble nitrogen, ammonium-nitrogen, total phosphorus, total soluble phosphorus, soluble reactive phosphorus, dissolved iron, dissolved manganese, chlorophyll, and phaeopigments using standard methods (Barko et al. 1993). Secchi disk transparency was measured to the nearest 1 cm. Depth profiles (0.25-m intervals) of water temperature, dissolved oxygen, pH, and conductivity were determined *in situ* using a Hydrolab Surveyor III. The Hydrolab was precalibrated with standard buffers and an independently determined dissolved oxygen measurement (Winkler Method, APHA 1992).

At biweekly to monthly intervals, spatial variations in *in situ* variables were monitored in Lower Peterson and Third Lakes. Five transects were established on Lower Peterson Lake and six transects were established on Third Lake (Barko et al. 1993). Two to five stations were located on each transect. Hydrolab measurements were made 0.1 m below the surface and 0.1 m above the bottom at each lake station between 0900 and 1400 h on each date.

During the winter months (December 1992-March 1993), Lower Peterson and Schmoker's Lakes exhibited water temperatures near zero throughout the water column (Fig. 8) as a result of cool water discharges from Upper Peterson Lake through the culvert. In contrast, Clear, First, and Third Lakes exhibited inverse stratification and warmer bottom temperatures (3-4 °C) during these winter months. While water column heating occurred in all lakes during the summer months (April-August 1993), Lower Peterson and Schmoker's Lakes were nearly isothermal with depth (Fig. 8). In particular, Lower Peterson Lake was isothermal throughout the year (Fig. 9) as a result of high velocity discharges from the culvert. Clear, First, and Third Lakes, however, exhibited intermittent periods of stratification during the summer (Fig. 8). In particular, stratification was observed in Third Lake during May, mid-June, late July, and August (Fig. 9).

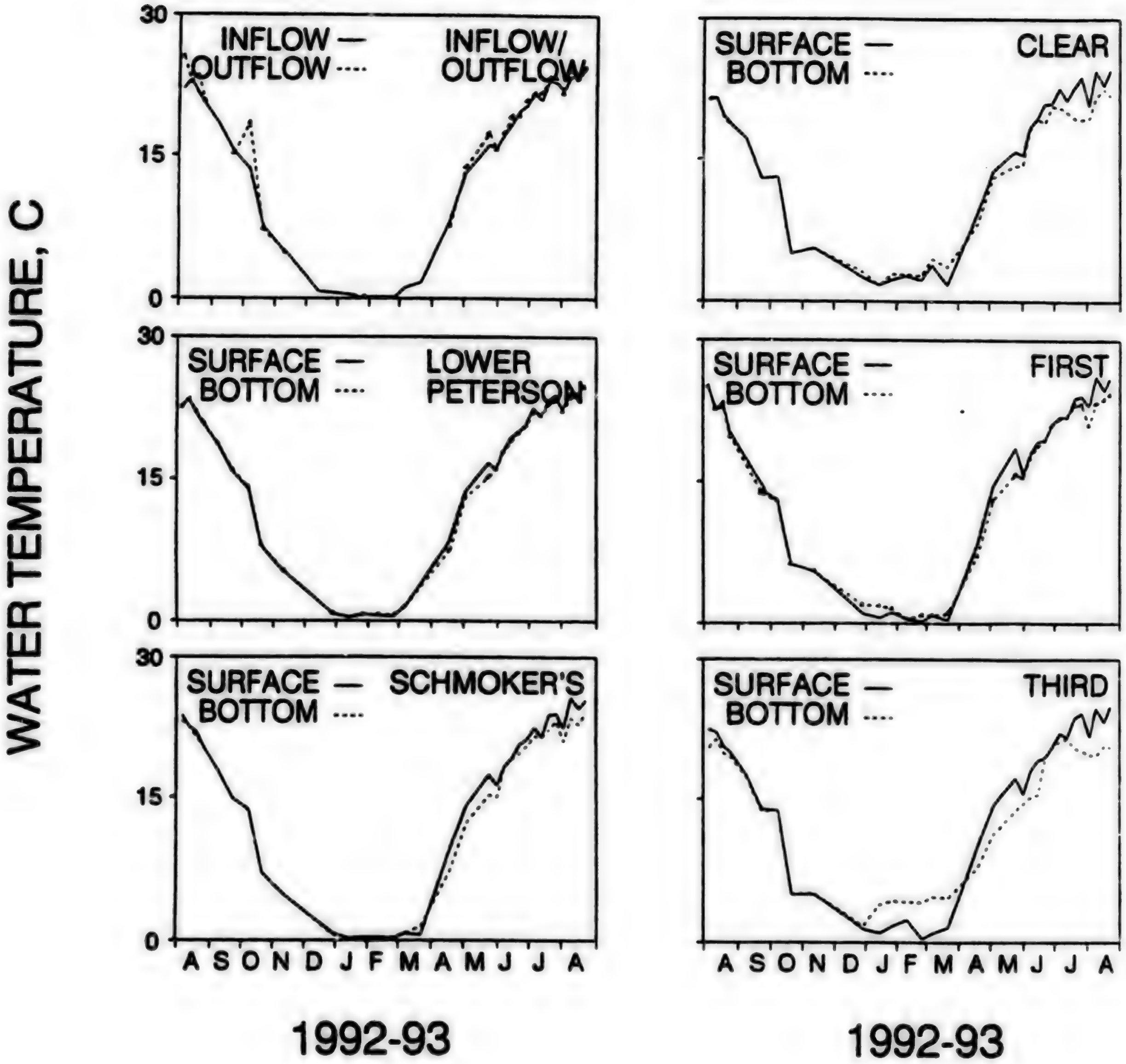

Figure 8. Seasonal variations in water temperatures of the inflow and the outflow, and water temperatures measured 0.1 m below the water surface and 0.1 m above the sediment in Lower Peterson, Schmoker's, Clear, First, and Third Lakes

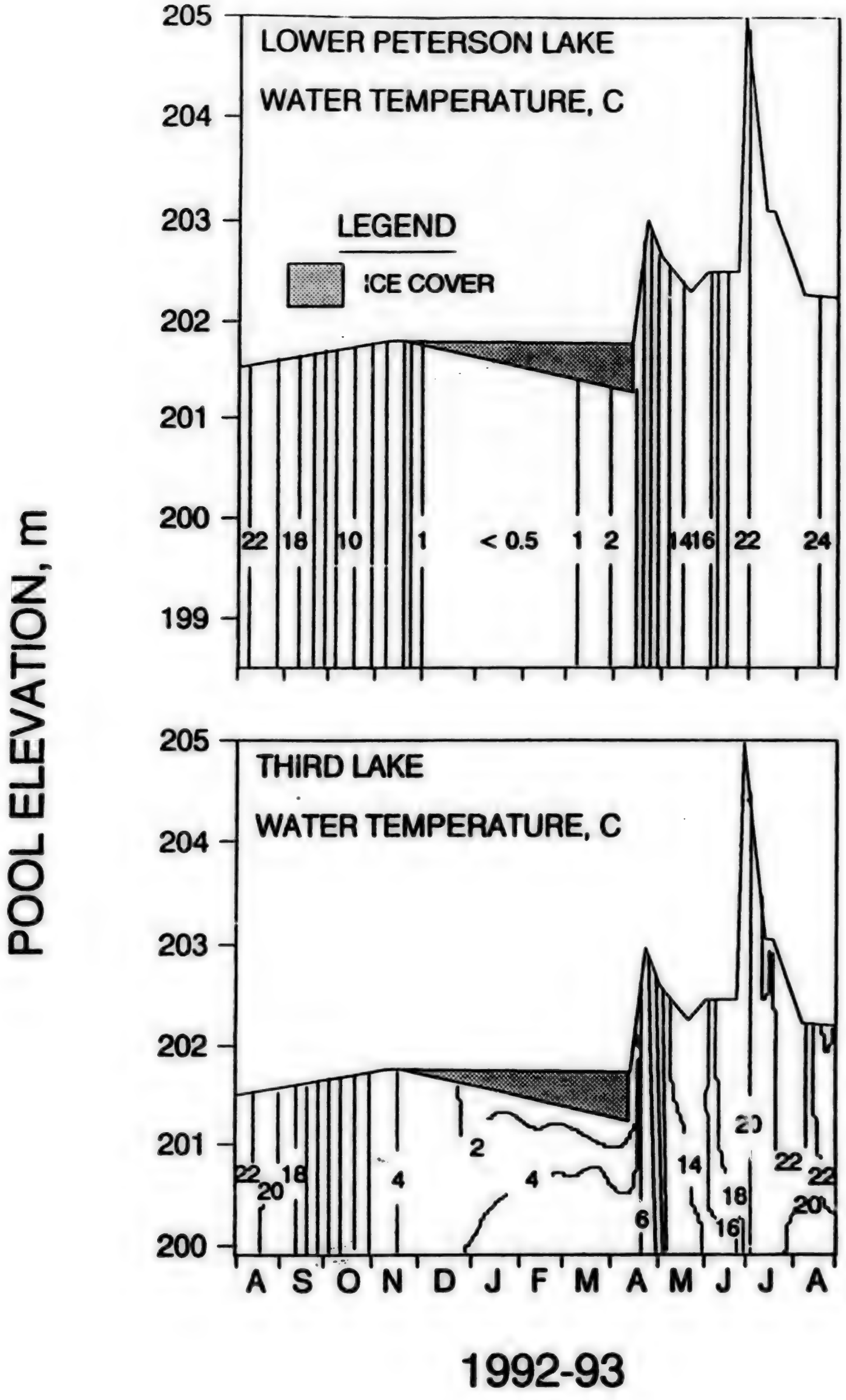

Figure 9. Seasonal and vertical variations in water temperature (°C) in Lower Peterson and Third Lakes

Both Lower Peterson and Schmoker's Lakes exhibited relatively high dissolved oxygen concentrations at the surface and bottom throughout the year, due to the inflow of oxygen-rich water from Upper Peterson Lake (Fig. 10). Concentrations of dissolved oxygen were nearly homogeneous with depth throughout the year in Lower Peterson Lake, which coincided with isothermal conditions (Fig. 9). Clear, First, and Third Lakes exhibited different patterns of dissolved oxygen variations compared to the other lakes. Dissolved oxygen concentrations approached zero under the ice in these particular lakes during January, and the bottom waters of Third Lake remained anoxic until the end of March (Fig. 10). During the summer, anoxic conditions occurred during July in Clear Lake and during intermittent periods from May through August in Third Lake (Fig. 10). These periods of anoxia coincided closely with the occurrence of stratification (Fig. 8) and are more clearly illustrated for Third Lake in Figure 11.

Seasonal variations in conductivity (Fig. 12) suggested that much of the flow from the culvert was moving directly through Lower Peterson and Schmoker's Lakes, bypassing the other lakes. Lower Peterson and Schmoker's Lakes and the outflow exhibited nearly identical fluctuations in conductivity throughout the year. Clear, First, and Third Lakes, in contrast, exhibited much different patterns than the other lakes throughout much of the year, suggesting isolation from the influences of flow. During late June, however, abnormally high storm inflows resulted in a marked increase in the tailwater elevation at Lock and Dam 4 and movement of water into the Finger Lakes through the outflow channel via the Zumbro and Mississippi Rivers. Conductivity values reflected this large influx of water, as shown by a marked depression in concentration in late June through early July in all the lakes.

During the autumn (August through November 1992), concentrations of suspended seston, particulate organic matter, and chlorophyll (Figs. 13, 14, and 15) were generally greatest in Clear and First Lakes, suggesting greater primary production. However, concentrations of these variables were lowest in Third Lake during the same period, which may be associated with possible negative influences of the extensive macrophyte community on phytoplankton production and sediment resuspension in this lake.

During the ice-free period of 1993 (April-August), concentrations of suspended seston, particulate organic matter, and chlorophyll exhibited a bimodal pattern in all lakes (Figs. 13, 14, and 15). The bimodal pattern was most pronounced for chlorophyll, as concentrations were generally greatest in late April and early August and depressed in late June and early July in all lakes (Fig. 15). The marked decline in chlorophyll concentrations in late June and early July was associated with the period of high inflow, suggesting possible dilution and/or washout of algae. Concentrations of seston and biogenic matter generally increased from the inflow to the outflow in the region most affected by water discharge from the culvert (i.e., Lower Peterson and Schmoker's Lakes). This pattern suggested that there was a net export of biogenic matter from the chain of lakes.

Total nitrogen and phosphorus concentrations were very similar in the inflow, Lower Peterson and Schmoker's Lakes, and the outflow throughout the year, suggesting that flows from the culvert were regulating concentrations in this series of stations (Figs. 16 and 17). Clear, First, and Third Lakes exhibited much different patterns in total nitrogen and phosphorus concentrations, particularly during the winter period. Large peaks in total phosphorus concentrations in these particular lakes during the winter coincided with periods of stratification (Fig. 9) and anoxia (Fig. 11), suggesting internal loading of phosphorus from the sediments. Soluble reactive phosphorus concentrations increased substantially in Clear and Third Lakes during the same winter period, indicating that much of the phosphorus was in the dissolved form (Fig. 18). Ammonium-N concentrations also increased in Clear, First, and Third Lakes during the winter months as a result of anoxia and probable microbial transformations of nitrate to ammonium (Fig. 19).

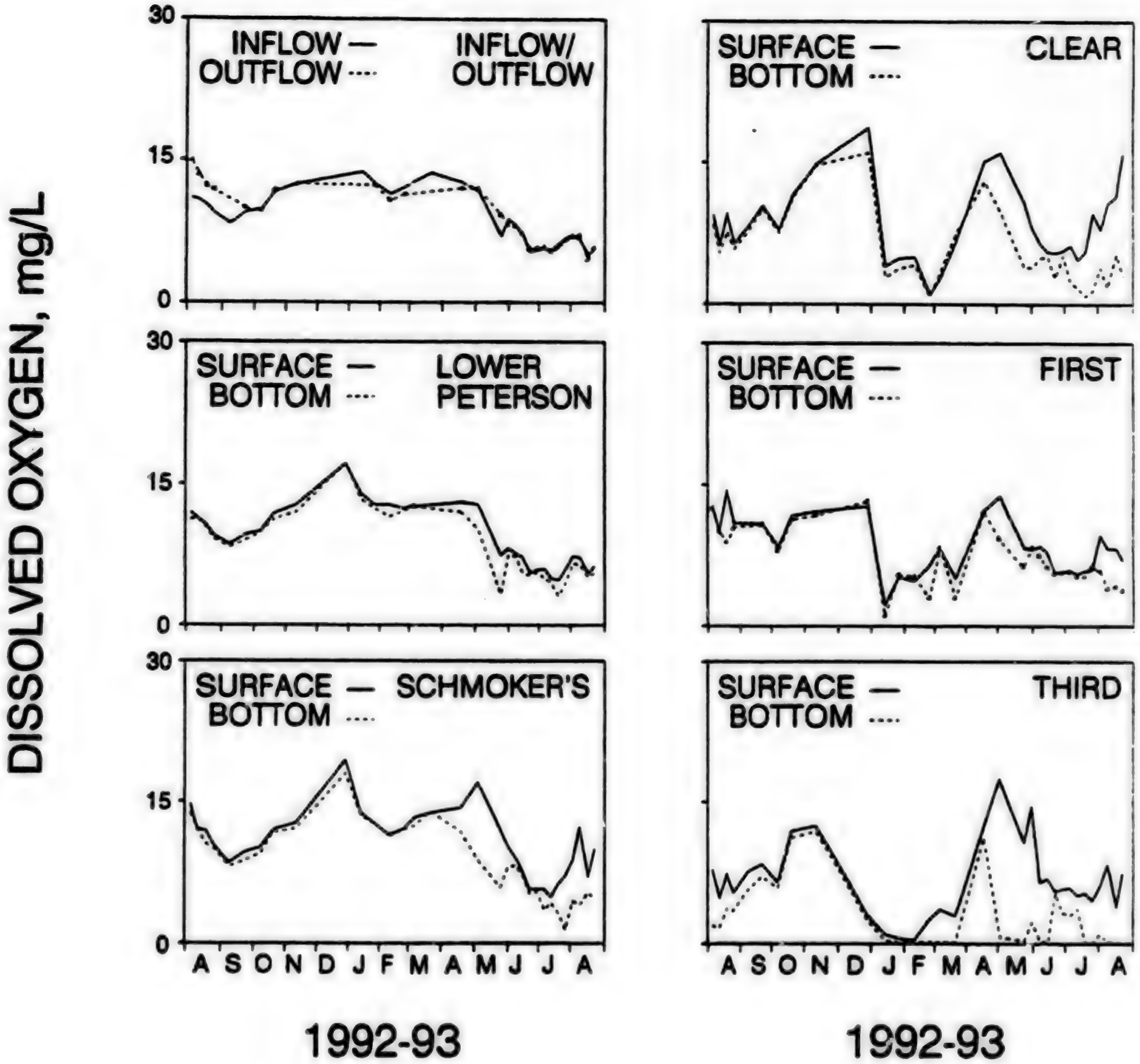

Figure 10. Seasonal variations in dissolved oxygen of the inflow and the outflow, and dissolved oxygen measured 0.1 m below the water surface and 0.1 m above the sediment in Lower Peterson, Schmoker's, Clear, First, and Third Lakes

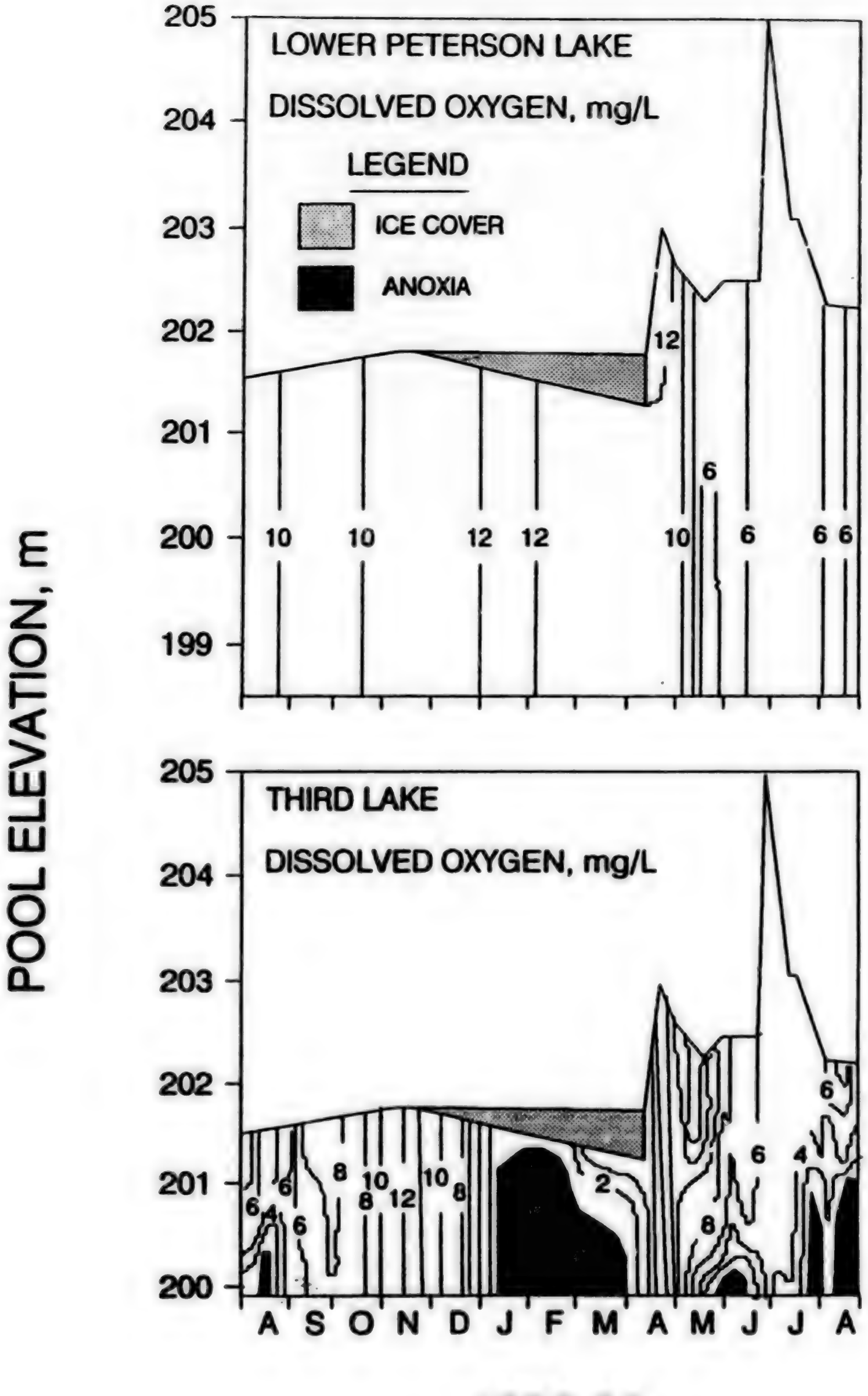

Figure 11. Seasonal and vertical variations in dissolved oxygen (mg/L) in Lower Peterson and Third Lakes

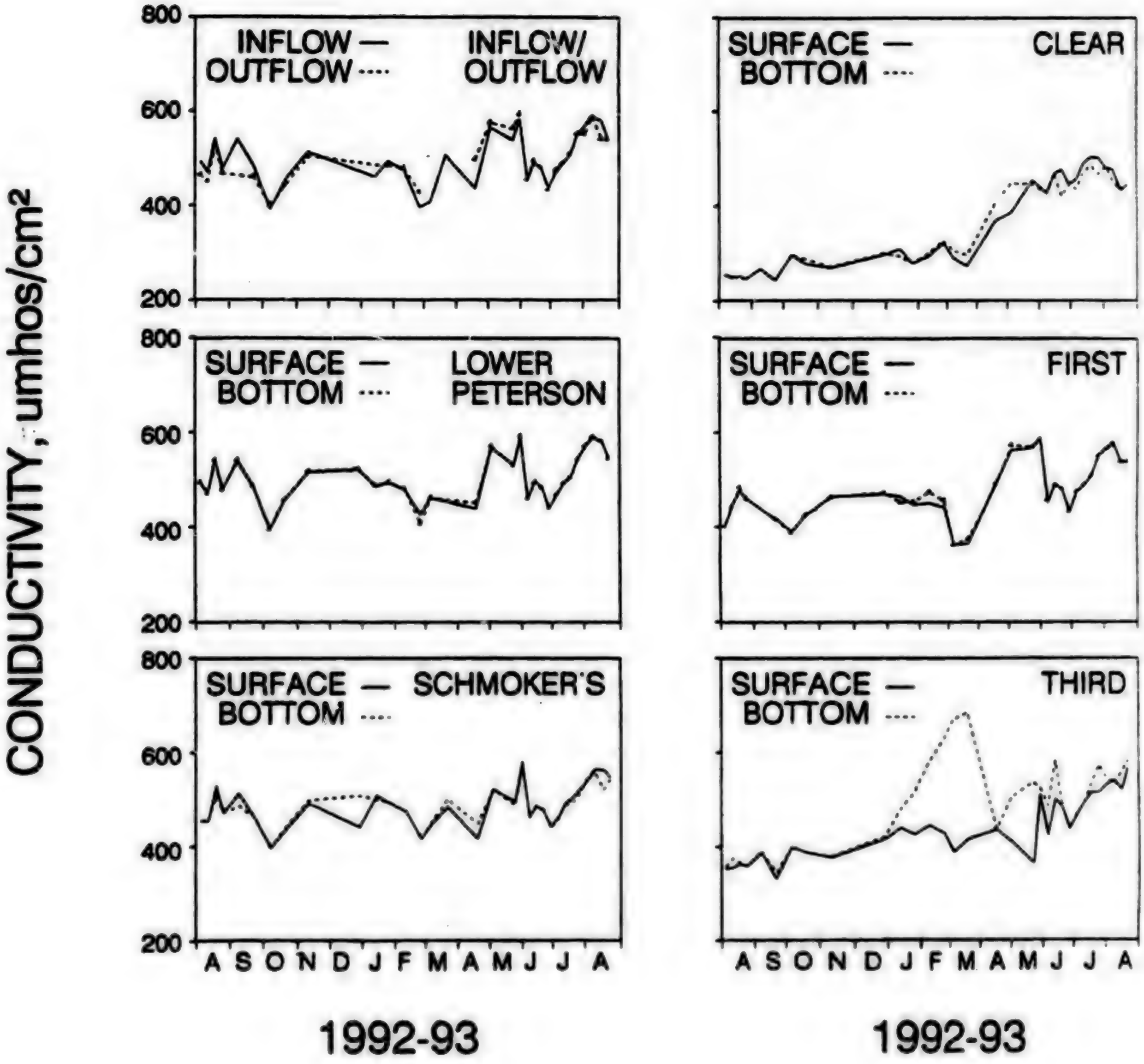

Figure 12. Seasonal variations in conductivity of the inflow and the outflow, and conductivity measured 0.1 m below the water surface and 0.1 m above the sediment in Lower Peterson, Schmoker's, Clear, First, and Third Lakes

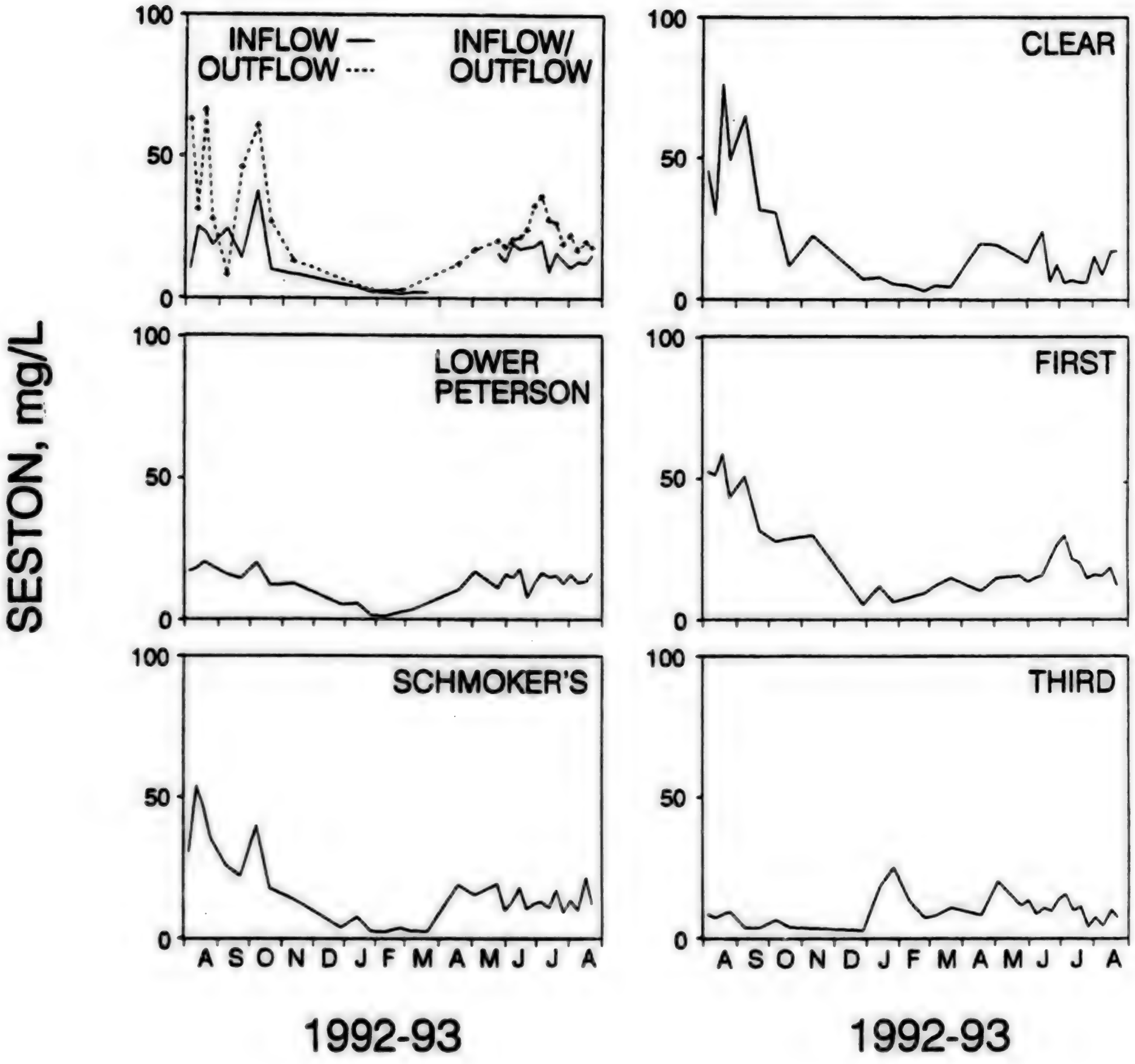

Figure 13. Seasonal variations in suspended seston of the inflow and the outflow, and suspended seston measured at mid-depth in Lower Peterson, Schmoker's, Clear, First, and Third Lakes

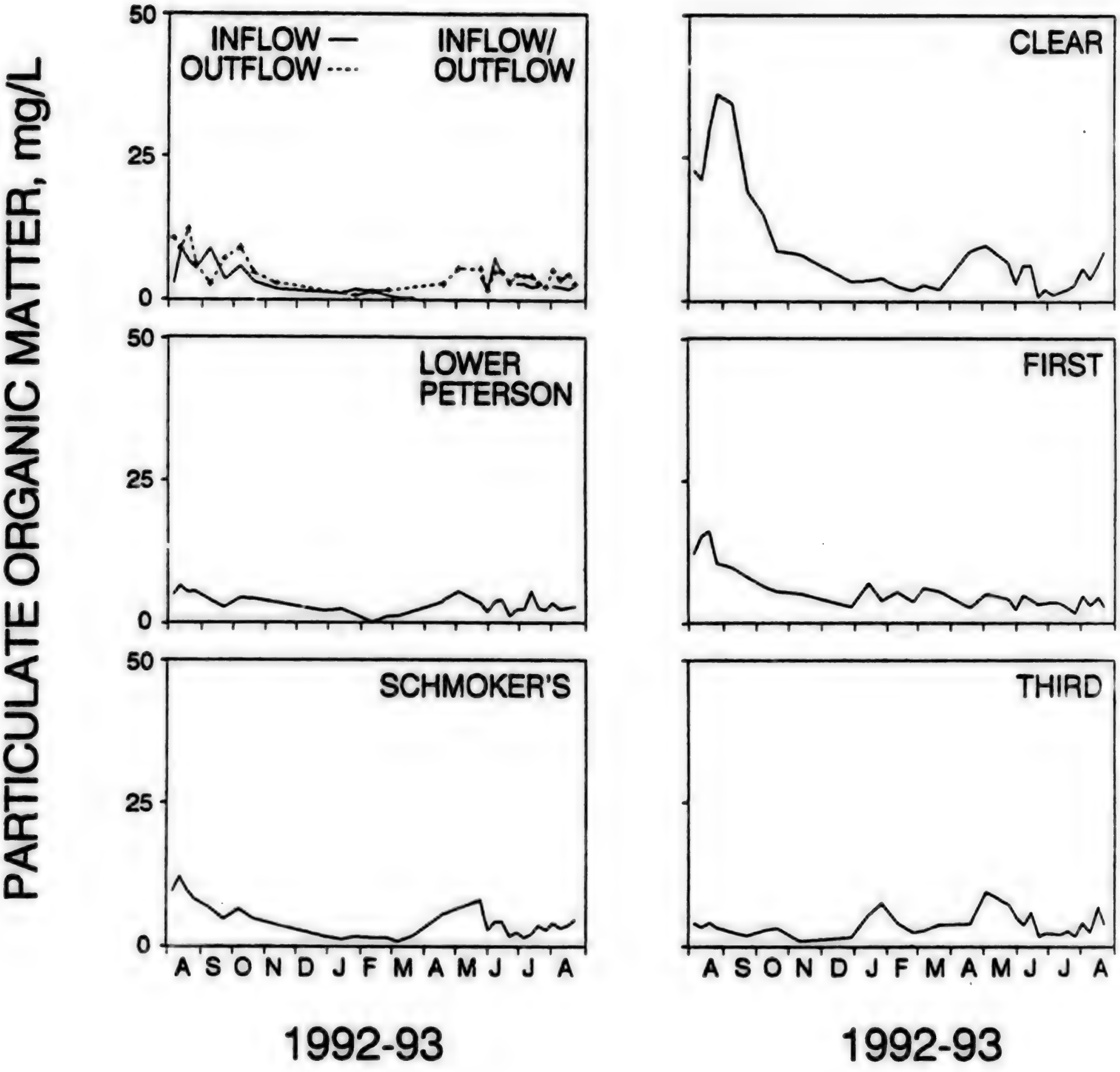

Figure 14. Seasonal variations in particulate organic matter of the inflow and the outflow, and particulate organic matter measured at mid-depth in Lower Peterson, Schmoker's, Clear, First, and Third Lakes

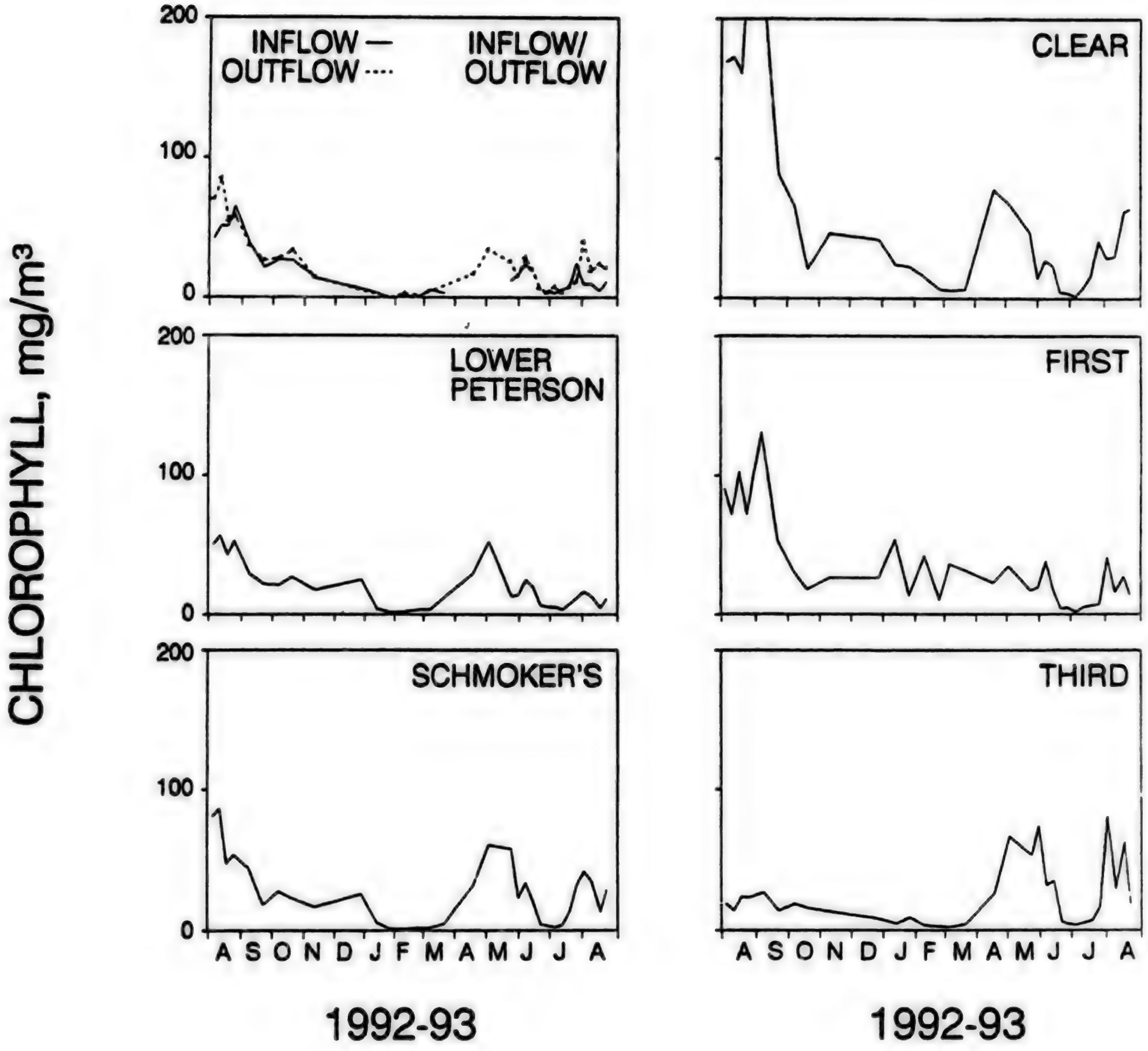

Figure 15. Seasonal variations in chlorophyll of the inflow and the outflow, and chlorophyll measured at mid-depth in Lower Peterson, Schmoker's, Clear, First, and Third Lakes

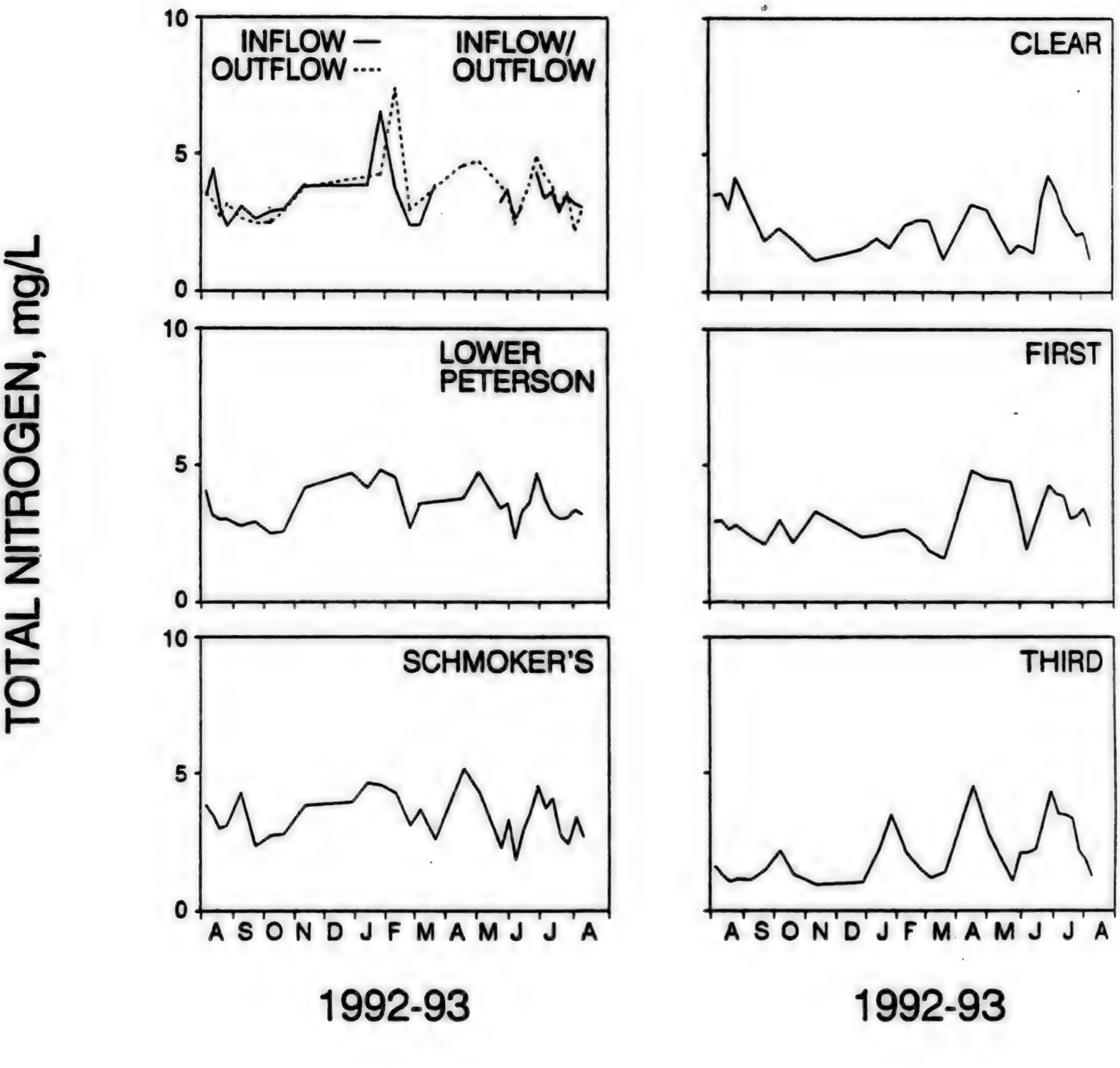

Figure 16. Seasonal variations in total nitrogen of the inflow and the outflow, and total nitrogen measured at mid-depth in Lower Peterson, Schmoker's, Clear, First, and Third Lakes

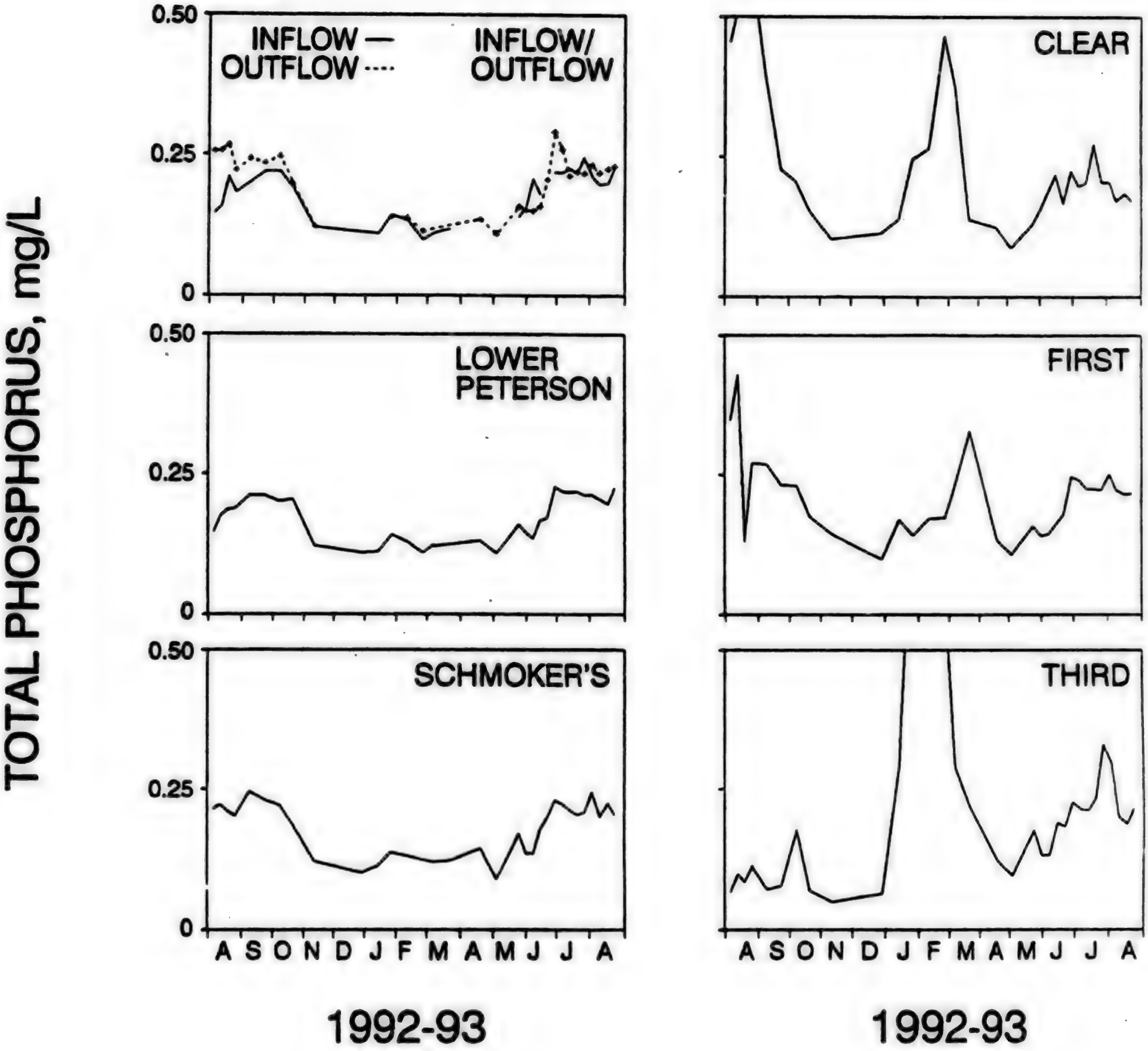

Figure 17. Seasonal variations in total phosphorus of the inflow and the outflow, and total phosphorus measured at mid-depth in Lower Peterson, Schmoker's, Clear, First, and Third Lakes

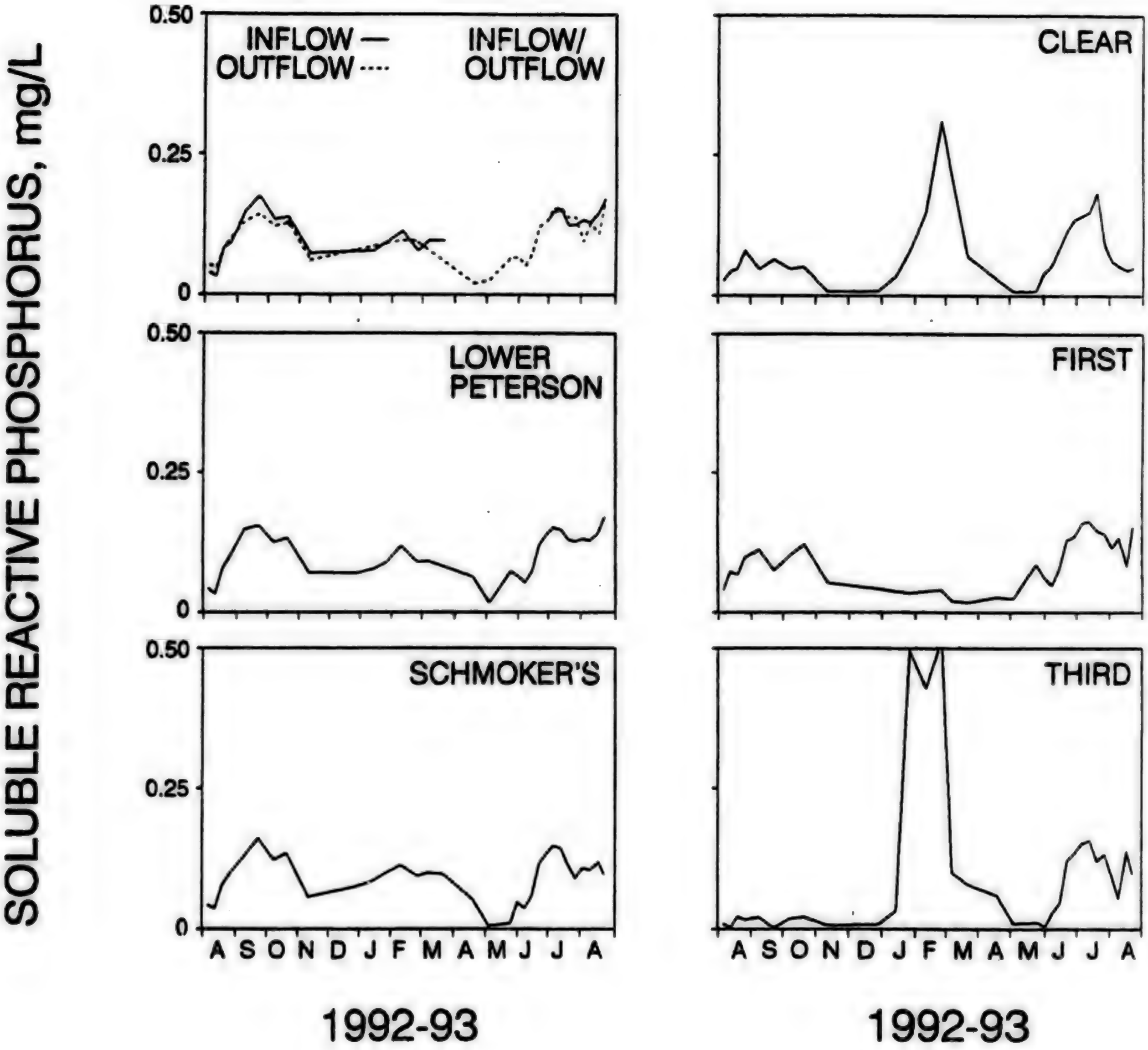

Figure 18. Seasonal variations in soluble reactive phosphorus (SRP) of the inflow and the outflow, and SRP measured at mid-depth in Lower Peterson, Schmoker's, Clear, First, and Third Lakes

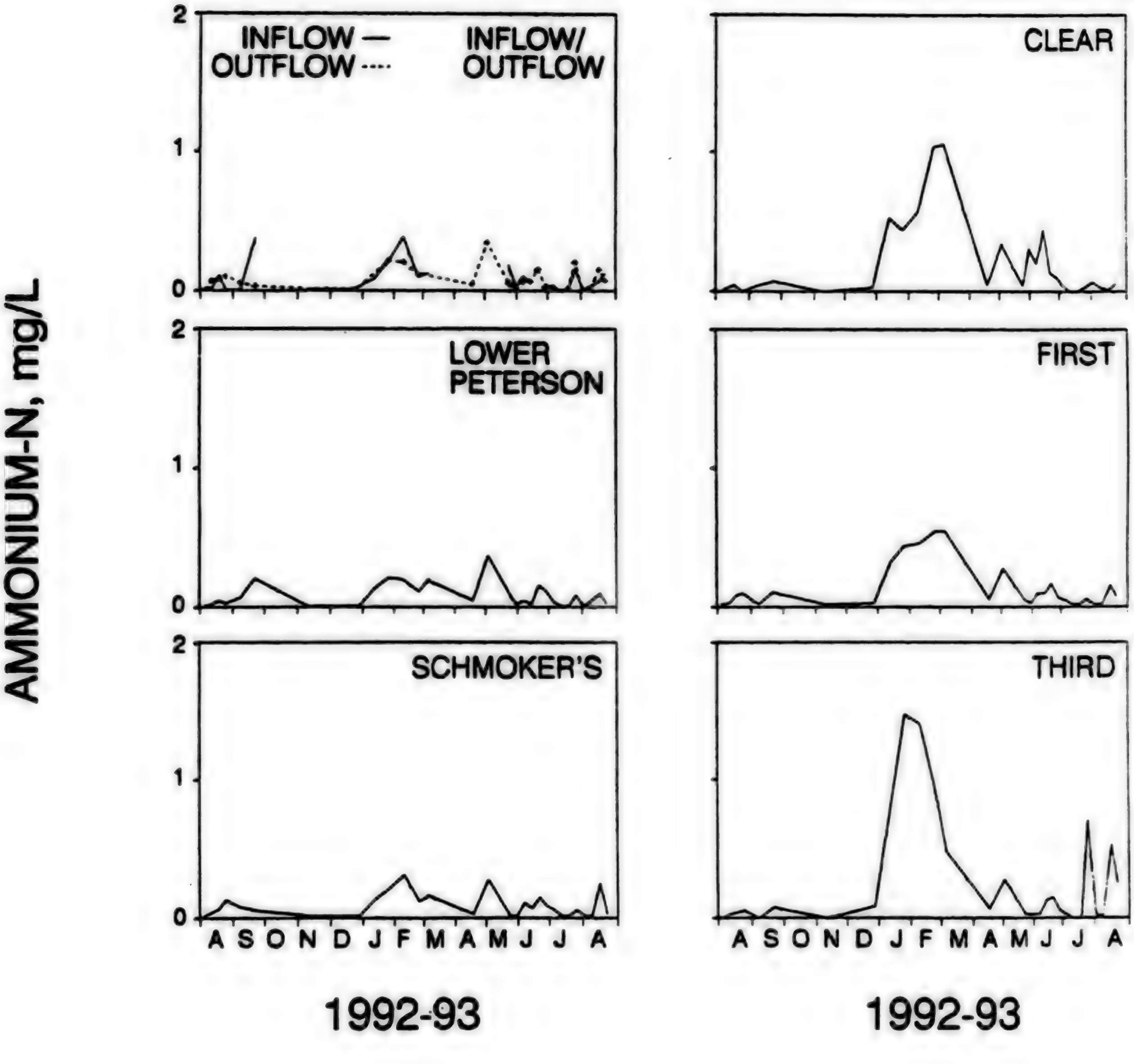

Figure 19. Seasonal variations in ammonium-N of the inflow and the outflow, and ammonium-N measured at mid-depth in Lower Peterson, Schmoker's, Clear, First, and Third Lakes

Variations in dissolved manganese and iron concentrations also reflected the isolation of Clear, First, and Third Lakes from the influences of flow via the culvert (Figs. 20 and 21). Whereas concentrations of these variables were low and constant in the inflow, Lower Peterson, Schmoker's, and the outflow, concentrations increased in the other lakes, particularly during periods of stratification and anoxia in the winter and the summer. Dissolved manganese concentrations increased markedly in Clear, First, and Third Lakes during the development of low oxygen concentrations in the winter. Dissolved manganese concentrations also increased in Clear and Third Lakes during the summer months, coinciding with intermittent periods of stratification and anoxia. In contrast, dissolved iron concentrations exhibited a major peak only in Third Lake during the winter months and was low in all of the lakes throughout the rest of the year. Differences in the behavior of dissolved iron and manganese may be related to differences in the oxidation-reduction potential required for solubilization of these elements.

Synopsis

These results indicate that flows from the culvert are moving directly through Lower Peterson and Schmoker's Lakes to the outflow, resulting in the isolation of the other lakes from the beneficial effects of flow. Thus, Clear, First, and Third Lakes can differ tremendously in water quality from Lower Peterson and Schmoker's Lakes. The summer flooding of 1993 clearly affected water quality conditions, as the large influx of water in late June through early July flushed all of the lakes. Concentrations of suspended seston, particulate organic matter, and chlorophyll generally decreased, while concentrations of total nitrogen and phosphorus generally increased in the lakes during this period.

While discharges from the culvert provide Lower Peterson and Schmoker's Lakes with relatively high dissolved oxygen concentrations, water temperatures are critically low in the winter to support the fishery. In contrast, the more isolated Clear, First, and Third Lakes exhibit intermittent and frequent periods of stratification and anoxia, particularly in the winter. Isolation of these lakes from flows results in periods of almost complete water column anoxia during the ice-covered period. During both winter and summer, anoxic conditions are often associated with the accumulation of high concentrations of soluble phosphorus, ammonium-N, dissolved manganese, and dissolved iron in many of the more isolated lakes. These results suggest that the sediments may be an important source of nutrients and metals to the water column under anoxic conditions in the isolated lakes.

Vegetation

Approach

Distribution and abundance of aquatic vegetation within the Finger Lakes were determined from field surveys and from aerial photography following procedures established in 1991. Submersed and floating-leaved aquatic vegetation was sampled during August and September 1993 at 10-m intervals along transects placed perpendicular to the shorelines in First, Third, Lower Peterson, and Schmoker's Lakes. Plants at each interval point (site) were sampled by casting a double-headed garden rake into the water at three different angles from the front of the boat. Species present on each rake cast were recorded to obtain frequency of occurrence data. After all three casts were made, each species was assigned an overall density rating from 1 to 4, based on

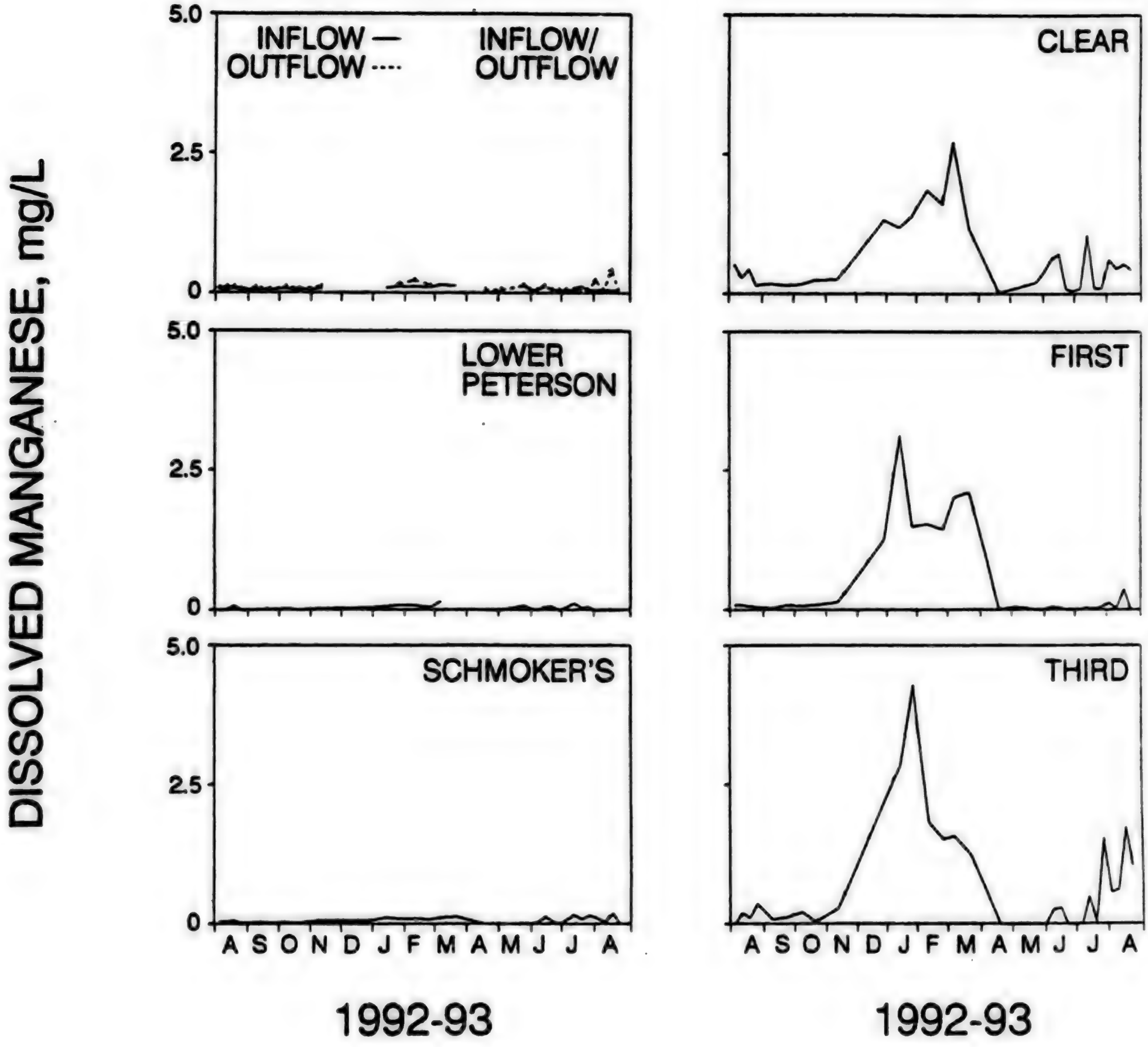

Figure 20. Seasonal variations in dissolved manganese of the inflow and the outflow, and dissolved manganese measured at mid-depth in Lower Peterson, Schmoker's, Clear, First, and Third Lakes

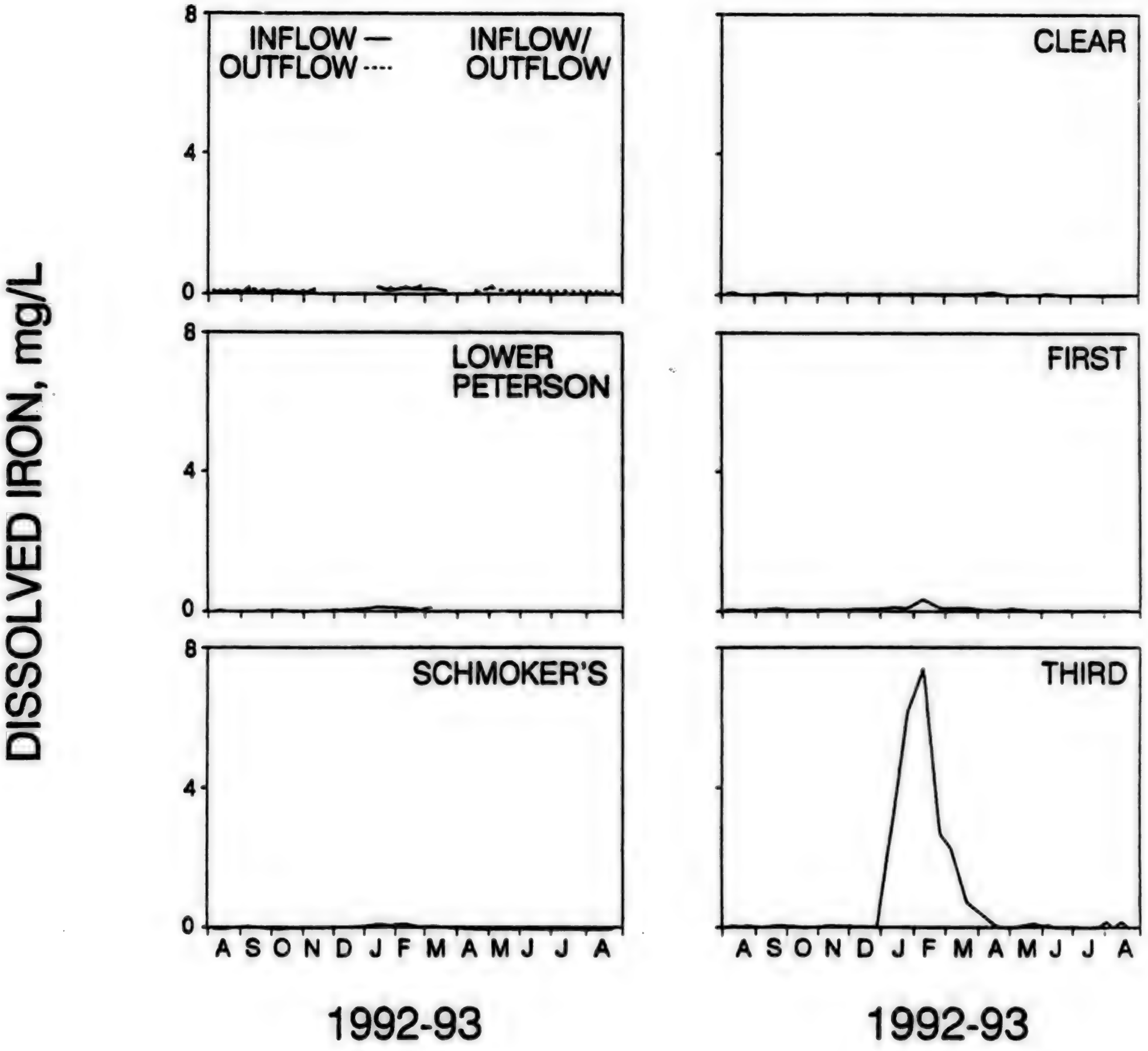

Figure 21. Seasonal variations in dissolved iron of the inflow and the outflow, and dissolved iron measured at mid-depth in Lower Peterson, Schmoker's, Clear, First, and Third Lakes

the number of rake casts in which the species appeared for each sampling site (i.e., 1991 procedures). Water depth was measured at each site.

Additional observations were made on the distribution of aquatic plants throughout the Finger Lakes using aerial photographs and ground exploration to locate beds and patches of submersed or floating aquatic plants that did not occur along transects. Information recorded for these additional sites included species presence.

The frequency of occurrence of a species is defined as $f_i = j_i/k$ where j_i = number of sample sites containing species i and k = total number of sample sites (by lake). Relative frequency of a species is defined as $rf_i = f_i/Ef$ where Ef = number of occurrences of all species (by lake). Relative density of a species is defined as $rd_i = dr_i/Edr$ where dr_i = density rating for species i and Edr = total density rating of all species (by lake). Importance value of a species is defined as $iv_i = rd_i + rf_i /2$. The maximum depth of plant growth is defined as the depth of the deepest sampling point where vegetation was found during the sampling period. Percent open area was calculated as the frequency of occurrence of sampling points with no vegetation that were found in water depths equal to or less than the maximum depth of plant growth.

Water level and water quality data were obtained for the period of study. Daily water levels for 1991 through 1993 were obtained for the Dam 4 tailwater gage operated by the U.S. Army Corps of Engineers. Since the hydrology of the Finger Lakes is closely linked to changes in Lock and Dam 4 tailwater elevations (Barko et al. 1993), daily tailwater elevation data were used to estimate water elevation fluctuations within the Finger Lakes. Differences in mean growing season (April 15-August 30) water levels for each month among years were analyzed using one-way ANOVAs. Duncan's multiple range tests were used to test differences among years.

Water quality data for the 1992 and 1993 growing season were obtained from the U.S. Army Corps of Engineers, Eau Galle Lab, Spring Valley, Wisconsin. These data included water temperature, Secchi depth, chlorophyll *a*, and seston concentrations. Temperatures were collected at discrete intervals (0.25-0.5 m) from surface to bottom. Chlorophyll *a* and seston were collected at the surface and bottom in 1992 and at mid-depth in 1993. Growing season means were calculated for each parameter. Annual changes in the number of vegetated sites and in maximum plant growth of each lake were compared to seasonal differences in mean monthly water levels, Secchi depths, and water temperatures using Spearman's rank correlation analysis.

Macrophyte Community Composition

Eight species of submersed and floating-leaved aquatic vegetation were found throughout the Finger Lakes in 1993, compared to 13 species in 1992 and 11 species in 1991 (Table 4). All eight species were found during the two previous surveys. *Ceratophyllum demersum*, *Myriophyllum spicatum*, and *Nymphaea tuberosa* were the three most dominant species, with a combined relative frequency of 90%. As in 1991 and 1992, Third Lake was the most heavily vegetated and Clear Lake the most sparsely vegetated of the lakes. However, the total number of vegetated sites within the lakes declined by 46% between 1991 and 1993. Most of the change in frequency of vegetated sites occurred between 1991 and 1992 in all lakes except Third Lake. Since 1992, the frequency of vegetated sites continued to decline in First, Third, and Lower Peterson Lakes, while Schmoker's Lake remained relatively stable (Table 4). Species richness was greatest in Lower Peterson Lake, where sediments were firmer (11, 9, and 7 species in 1991, 1992, and 1993, respectively; Table 5).

Table 4. Frequency of vegetated sites along transects for the Finger Lakes during 1991, 1992, and 1993 (as a percentage of total number of sites sampled)

Lake	1991	1992	1993
First	54	19	06
Lower Peterson	46	34	26
Schmoker's	42	26	23
Third	94	88	66

First Lake

Only 11% of sites vegetated in 1991 were still vegetated in 1993 (Table 5). Most of the decline in the number of vegetated sites can be attributed to a 1992 decrease in *Ceratophyllum* in the upper third of the lake. The open niche created by the decline in *Ceratophyllum* was not invaded by other species in 1993; percent open water changed from 44.5% in 1991 to 86.4% in 1993. Mean depths occupied by vegetation in First Lake averaged between 0.31 and 0.50 m during 1991 and 1992. According to depth data collected along the transects, First Lake, which is the shallowest of the four lakes, averaged 0.43 m in 1991 and 1992. During 1993, mean depths were greater, averaging 0.8 m. Most species still growing in the lake were found in water depths up to 0.7 m.

Mean growing season Secchi depth was deeper in 1993 (53 cm compared to 36 cm in 1992). Mean seasonal water temperature was higher in 1993 (19.8 °C) than in 1992 (17.7 °C). Mean growing season chlorophyll *a* concentration was 17.0 mg/m^3 in 1993 and 81.5 mg/m^3 in 1992. Mean growing season seston was 17.5 mg/L in 1993 and 81.5 mg/L in 1992.

Lower Peterson Lake

Fifty-six percent of sites vegetated in 1991 were still vegetated in 1993 (Table 5). Nearly all 10 species found in 1991, with the exception of *Nymphaea*, have decreased in frequency of occurrence and in importance values. With the decline in submersed species, *Nymphaea* has gained in importance but not in frequency (Table 5). Percentage of open water sites increased from 23.0% in 1991 to 54.6% in 1993, indicating the existence of open niches at water depths capable of supporting submersed species. Mean depths occupied by vegetation in Lower Peterson Lake ranged from 0.44 to 0.51 m during 1991 and 1992 and averaged 0.63 m in 1993. Submersed and floating species within the lake are distributed around the periphery of the lake, where depths are shallowest. According to data collected along the transects, Lower Peterson mean depths ranged from 0.88 m to 1.00 m in 1991 and 1992, and increased to 1.33 m in 1993.

As in First Lake, mean growing season Secchi depth was deeper in 1993 (58 cm compared to 45 cm in 1992). Mean seasonal water temperature was higher in 1993 (19.7 °C) than in 1992 (17.4 °C). Mean growing season chlorophyll *a* concentration was 14.5 mg/m^3 in 1993 and 48.3 mg/m^3 in 1992. Mean growing season seston was 14.1 mg/L in 1993 and 22.7 mg/L in 1992.

Table 5. Community attributes in the Finger Lakes by year

Species	First Lake				Lower Peterson				Schmoker's Lake				Third Lake			
	Freq	Relative freq	Relative density	IV	Freq	Relative freq	Relative density	IV	Freq	Relative freq	Relative density	IV	Freq	Relative freq	Relative density	IV
1991																
Ceratophyllum demersum	45	72.55	84.68	78.62	24.0	22.86	19.26	21.06	16	21.74	17.14	19.44	92	69.70	77.55	73.62
Elodea canadensis	1	1.96	0.90	1.43	4.0	4.29	2.96	3.62	-	-	-	-	2	1.52	0.51	1.01
Myriophyllum spicatum	7	11	7.21	9.49	20.0	21.43	22.22	21.83	38	52.17	60.00	56.09				
Najas flexilis	-	-	-	-	-	-	-	-	2	4.35	5.71	5.03	-	-	-	-
Nelumbo lutea	-	11.43	16.30	13.86	11.0	11.43	16.30	13.86	-	-	-	-	-	-	-	-
Nymphaea tuberosa	9	3.92	2.70	3.31	25.0	25.71	27.41	26.56	1	13.04	8.57	10.81	38	28.79	21.94	25.36
Potamogeton americanus	4	5.88	2.70	4.29	-	-	-	-	2	4.35	5.71	5.03	-	-	-	-
Potamogeton crispus	2	3.92	1.80	2.86	-	-	-	-	-	-	-	-	-	-	-	-
Potamogeton zosteriformis	-	-	-	-	4.0	4.29	2.22	3.25	-	-	-	-	-	-	-	-
Vallisneria americana	-	-	-	9.81	10.0	10.00	9.63	9.81	-	-	-	-	-	-	-	-
Zosterella dubia	-	-	-	3.60	-	-	-	-	3	4.35	2.86	3.60	-	-	-	-
1992																
Ceratophyllum demersum	12	41.38	44.44	42.91	8	12.50	7.45	9.97	2	15.38	14.29	14.84	82	47.06	64.25	55.66
Elodea canadensis	2	6.90	13.89	10.39	1	2.08	1.06	1.57	-	-	-	-	-	-	-	-
Myriophyllum spicatum	7	17.24	16.67	16.95	10	14.58	13.83	14.21	21	76.92	80.95	78.94	-	-	-	-
Nelumbo lutea	-	-	-	-	8	12.50	12.77	12.63	1	7.69	4.76	6.23	-	-	-	-
Nuphar advena	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nymphaea tuberosa	6	20.69	19.44	20.07	22	37.50	48.94	43.22	-	-	-	-	45	25.88	21.26	23.57
Potamogeton crispus	1	3.45	2.78	3.11	1	2.08	1.06	1.57	-	-	-	-	22	12.94	7.25	10.09
Potamogeton foliosus	-	-	-	-	-	-	-	-	-	-	-	-	2	1.18	0.48	0.83

Table 5. Continued

Species	First Lake				Lower Peterson				Schmoker's Lake				Third Lake			
	Freq	Relative freq	Relative density	IV	Freq	Relative freq	Relative density	IV	Freq	Relative freq	Relative density	IV	Freq	Relative freq	Relative density	IV
Potamogeton pectinatus	-	-	-	-	-	-	-	-	-	-	-	-	20	11.76	6.28	9.02
Vallisneria americana	-	-	-	-	1.80	10.42	9.57	10.00	-	-	-	-	-	-	-	-
Zosterella dubia	-	-	-	-	1.25	8.33	5.32	6.83	-	-	-	-	-	-	-	-
1993																
Ceratophyllum demersum	5	33.33	36.84	35.09	9	18.92	16.00	17.46	2	8.33	6.25	7.29	62	71.43	86.32	78.88
Elodea canadensis	1	8.33	15.79	12.06	-	-	-	-	-	-	-	-	-	-	-	-
Myriophyllum spicatum	3	25.00	15.79	20.39	5	10.81	8.00	9.41	21	75.00	75.00	75.00	-	-	-	-
Nelumbo lutea	-	-	-	-	7	13.51	12.00	12.76	2	8.33	12.50	10.42	-	-	-	-
Nymphaea tuberosa	3	25.00	21.05	23.03	24	48.65	54.0	51.32	2	8.33	6.25	7.29	25	28.57	13.68	21.12
Potamogeton crispus	-	-	-	-	1	2.70	2.00	2.35	-	-	-	-	-	-	-	-
Potamogeton nodosus	1	8.33	10.53	9.43	-	-	-	-	-	-	-	-	-	-	-	-
Vallisneria americana	-	-	-	-	3	5.41	8.00	6.70	-	-	-	-	-	-	-	-

IV = Importance Value

Schmoker's Lake

Fifty-five percent of sites vegetated in 1991 were still vegetated in 1993 (Table 5). *Ceratophyllum* and *Myriophyllum*, the two most common species in the lake, were responsible for most of the observed change. Both species declined in frequency of occurrence. Mean depths along transects in Schmoker's Lake were 0.54 m in 1991 and 1992 and averaged 0.96 m in 1993. Species occurred in mean depths of 0.35 and 0.37 m in 1991 and 1992, and in mean depths of 0.80 m in 1993.

Mean growing season Secchi depth was deeper in 1993 (58.7 cm) compared to in 1992 (35.4 cm). Mean seasonal water temperature was higher in 1993 (19.8 °C) than in 1992 (18.2 °C). Mean growing season chlorophyll *a* concentration was 25.7 mg/m^3 in 1993 and 61.7 mg/m^3 in 1992. Mean growing season seston was 14.1 mg/L in 1993 and 38.5 mg/L in 1992.

Third Lake

Between 1991 and 1993, 72% of vegetated sites remained so, with the majority of sites dominated by the presence of *Ceratophyllum* (Table 4). Species diversity decreased in 1993 compared to in 1992 (Table 5) and percent open water increased from 2.1 in 1991 to 26.0 in 1993. Mean depths along transects ranged from 0.73 to 0.77 m in 1991 and 1992, and increased to 1.1 m in 1993. Submersed and floating-leaved macrophytes occupied mean depths of 0.68 m in 1991 and 1992 and mean depths of 0.88 m in 1993.

Secchi depths were similar in Third Lake during 1992 (66.3 cm) and 1993 (68.8 cm). Mean seasonal water temperature was higher in 1993 (19.0 °C) than in 1992 (17.7 °C). Mean growing season chlorophyll *a* concentration was 31.8 mg/m^3 in 1993 and 36.1 mg/m^3 in 1992. Mean growing season seston was 14.1 mg/L in 1993 and 13.2 mg/L in 1992.

Synopsis

Our surveys indicate all four lakes have unstable plant communities that change over time in size of beds (frequency of occurrence) and, to a lesser extent, in species composition. During the last 3 years, a decline has occurred in the abundance of submersed and floating-leaved vegetation. Three species, *Ceratophyllum demersum*, *Myriophyllum spicatum*, and *Nymphaea tuberosa*, have remained dominant throughout all sampling years, although the frequency of these species has declined in most areas. Patterns of less frequently occurring species are more difficult to detect since their presence is more likely to be overlooked. In 1992, species that typically senesce by mid- to late summer were still prevalent, likely as a result of cooler than normal seasonal temperatures and low water levels in May and June.

Our data failed to reveal significant correlations between the frequency of occurrence or maximum depth of plant growth with Secchi depths, water temperatures, or water levels. However, with the exception of Third Lake, most of the declines in frequency of occurrence occurred in 1992, a year when Secchi depths were less and suspended solids and chlorophyll *a* concentrations were relatively high in Schmoker's, Lower Peterson, and First Lakes. In contrast, Third Lake maintained similar mean Secchi depths, seston, and chlorophyll *a* concentrations, and maintained a relatively stable plant population during 1992 and 1993. Thus, light availability is one likely factor influencing population dynamics within the Finger Lakes.

Although Secchi depths improved in 1993 compared to in 1992, and suspended solids and chlorophyll *a* concentrations decreased, the prolonged season of high water levels in 1993 likely resulted in less than optimal conditions for plant bed expansion beyond 1992 levels. Existing plant beds were subjected to deeper than normal growing conditions and higher flows which may have scoured some areas or buried others under new deposits.

Although declines in vegetation have occurred during the last 3 years, it is not possible to predict whether the trend will continue. The Finger Lakes are subjected to wide variations in water quality and water levels from year to year, and vegetation patterns are likely influenced by these changes. Installation of the culvert system will likely result in more uniform water and sediment conditions among lakes, which will affect the distribution of plant beds and species. Other factors, such as sediment nutrient availability, grazing impacts of carp, and pathogens, have not been addressed in this report, yet also need to be considered to better understand the ecology of the aquatic plant community.

Macroinvertebrates

The relatively sessile nature of benthic macroinvertebrates make them susceptible to effects associated with alteration of flow regimes. High flows scour the substrate and dislodge benthos (Anderson and Lehmkuhl 1968), reduced flows frequently dewater portions of impounded rivers and lead to desiccation (Fisher and LaVoy 1972; Kroger 1973; Ward 1976), and flow variations can alter drift and feeding behavior (Scullion and Sinton 1983; Perry and Perry 1986).

Studies on invertebrates exposed to manipulated flow regimes are frequently conducted below dams on large rivers (Ward 1976; Morgan et al. 1991), where the magnitude of the flow alteration is usually great (Irvine 1985; Perry and Perry 1986; Weisberg et al. 1990). A frequently observed response to altered flow regimes in the reaches downstream of hydroelectric dams is an enhancement of invertebrate abundance, sometimes at the expense of species richness (Petts 1984). However, Morgan et al. (1991) reported a doubling in total density of invertebrates following flow alteration in the Patuxent River, without a concomitant reduction in diversity.

Littoral zones support a diverse, abundant, and productive invertebrate fauna, especially when vegetated (Lim and Fernando 1978; Gilinsky 1984). Epiphytic invertebrates are often substantially more abundant than littoral benthos (Soszka 1975; Beckett et al. 1992). These macrophyte-associated invertebrates provide an important food resource for juvenile and adult fish (Mittelbach 1984) and waterfowl (Krull 1970).

Our research objectives were to compare the taxonomic composition, density (number of invertebrates/unit area), and biomass (mass/unit area) of macroinvertebrates among three habitat types (macrophyte beds, sedimentary substrate beneath macrophyte beds, and sedimentary substrate in open water) in Clear, Lower Peterson, and Third Lakes.

Approach

A stratified random sampling design was employed to sample macroinvertebrates from the Finger Lakes. In each lake, eight sampling sites were randomly selected in each of three habitat types (strata): macrophyte beds, sedimentary substrate beneath macrophyte beds, and sedimentary substrate in open water. However, not all habitat types were present in all lakes. The sampling design is shown in Table 6. Sampling periods coincide roughly with the maximum (August) and

Table 6. Summary of experimental design for sampling macroinvertebrates from the Finger Lakes showing the number of samples obtained on an annual basis. Samples are obtained at maximum (August) and minimum (May) densities of rooted aquatic plants.

Lake, habitat type	Maximum macrophyte abundance	Minimum macrophyte abundance
Clear Lake[a]		
Open water	8	8
Lower Peterson Lake		
Open water	8	8
Sediment-vegetation	8	8
Vegetation	8	--[b]
Third Lake		
Open water	8	8
Sediment-vegetation	8	8
Vegetation	8	--[b]
Total number of samples	56	40

[a] Vegetative areas in Clear Lake are too sparse to sample.
[b] Epiphytic invertebrates are sampled only at periods of maximum macrophyte abundance.

minimum (May) densities of rooted aquatic plants. All sampling sites were located using Universal Transverse Mercator (UTM) coordinates obtained from a 1:24,000-scale USGS topographic map of the Finger Lakes area.

When sampling sedimentary substrates in open water and beneath the macrophyte beds, one grab sample was taken with a petite ponar dredge (0.0225 m^2) from each sampling site. Samples were washed through a 595-μm sieve, and the contents retained on the sieve were preserved in 10% formalin. When sampling epiphytic macroinvertebrates, we cut a standard length (50 cm for emergent species and 25 cm for submergent species) of non-branching stem from the uppermost portion of five plants of the predominant macrophyte species at each site. Macrophytes and associated invertebrates were preserved in 10% formalin.

In the laboratory, invertebrates were sorted from the substrate, identified to the lowest practical level, and enumerated. In addition, wet-weight biomass (to the nearest 0.001 g) was determined for invertebrates grouped by family within each sample. Ten percent of the samples were re-sorted and re-identified to estimate the number of organisms missed during the initial sampling and to independently verify taxonomic identification.

Neither the density nor biomass data met the assumptions of parametric statistical analyses, even after transformation. Thus, all data were rank-transformed and subsequent analyses were performed on these rank-transformed data. All analysis of variance tests were done using the general linear models procedure in the Statistical Analysis System. Because we have only one season of data on epiphytic macroinvertebrates, they were not included in any statistical tests. Null hypotheses were rejected at $P \leq 0.05$. Data are expressed as mean plus or minus one standard error of the mean.

Differences in total invertebrate density and total biomass were compared between habitat types within a given lake and season (habitat effects), between seasons within a given habitat and lake (seasonal effects), and among lakes within a given habitat and season (lake effects). If a significant difference resulted from these comparisons, we employed orthogonal contrast statements to determine where these differences occurred.

The data contained within this report derive from sampling conducted in August 1991 and May 1992 only. The remaining samples from the preconstruction phase will be processed in 1994.

Density and Biomass of Macroinvertebrates

A total of 106 taxa, comprising 19 orders and 43 families, were found in the Finger Lakes. Invertebrate density was similar among lakes, with densities ranging from 1,948 to 4,187/m^2 in Clear Lake, 1,475 to 6,986/m^2 in Peterson Lake, and 1,281 to 3,929/m^2 in Third Lake (Table 7). Total biomass was more variable, ranging from 3,778 to 8,762 mg/m^2 in Clear Lake, 1,224 to 4,785 mg/m^2 in Peterson Lake, and 800 to 9,362 mg/m^2 in Third Lake.

Lake Effects

In open water, total invertebrate density was not significantly different among lakes in either August or May (Fig. 22). However, total biomass was significantly different among lakes in both August ($P = 0.002$) and May ($P = 0.015$), with invertebrates from Clear Lake having the highest biomass in both seasons (Fig. 22). There was no difference in total invertebrate biomass between Peterson and Third Lakes in either season.

In sedimentary substrate beneath macrophyte beds, neither total density nor total biomass was significantly different between lakes in either season (Fig. 22), probably the result of large variation in density, especially in Peterson Lake in August (coefficient of variation = 157%).

The only comparison of epiphytic invertebrates that can be made at this time is between Peterson and Third Lakes. Epiphytic invertebrates in Peterson Lake were about twice as abundant and had higher biomass compared to invertebrates from similar habitats in Third Lake (Table 7).

We were interested in the average weight of an organism in the Finger Lakes to determine if food resources for fish were concentrated in a particular lake. We calculated the mean weight by dividing the mean biomass by the mean density (Table 7). Interestingly, the mean weight of an organism in Clear Lake, a lake with sparse vegetation and low invertebrate diversity, was 1.94 mg in August. This is much greater than mean weights in either Peterson or Third Lakes, which ranged from 0.15 to 0.83 mg. In May, the mean weights were more uniform among lakes, averaging 2.1 mg in Clear Lake, 1.2 mg in Peterson Lake, and 2.2 mg in Third Lake.

Table 7. Mean density (± 1 SE), mean biomass (± 1 SE), and the mean organism weight (mg) of benthos in the Finger Lakes in August 1991 and May 1992. Means are based on eight samples within each habitat type within each lake. Three habitat types were sampled in most lakes: open water, substrate beneath vegetation beds, and vegetation.

Lake, habitat	August 1991			May 1992		
	Density[a]	Biomass[b]	Mean weight	Density	Biomass	Mean weight
Clear Lake[c]						
Open water	1,948 ± 159	3,778 ± 470	1.94	4,187 ± 622	8,762 ± 1,078	2.09
Peterson Lake						
Open water	1,475 ± 314	1,224 ± 247	0.83	3,331 ± 249	3,630 ± 518	1.09
Sediment-vegetation	6,986 ± 3,883	4,053 ± 2,054	0.58	3,730 ± 536	4,785 ± 653	1.28
Vegetation	0.029 ± 0.016	0.005 ± 0.002	0.33	--[d]	--[d]	--
Third Lake						
Open water	1,281 ± 830	880 ± 560	0.69	2,169 ± 854	4,499 ± 1,883	2.07
Sediment-vegetation	2,578 ± 450	1,752 ± 275	0.68	3,929 ± 1,025	9,362 ± 2,552	2.38
Vegetation	0.016 ± 0.006	0.003 ± 0.001	0.15	--[d]	--[d]	--

[a] Density reported as number/m^2 in open water and sediment-vegetation habitats and as number/m in vegetative habitats.

[b] Biomass reported as mg/m^2 in open water and sediment-vegetation habitats and as mg/m in vegetative habitats.

[c] Vegetative areas in Clear Lake were too sparse to sample.

[d] Vegetation not sampled in May 1992

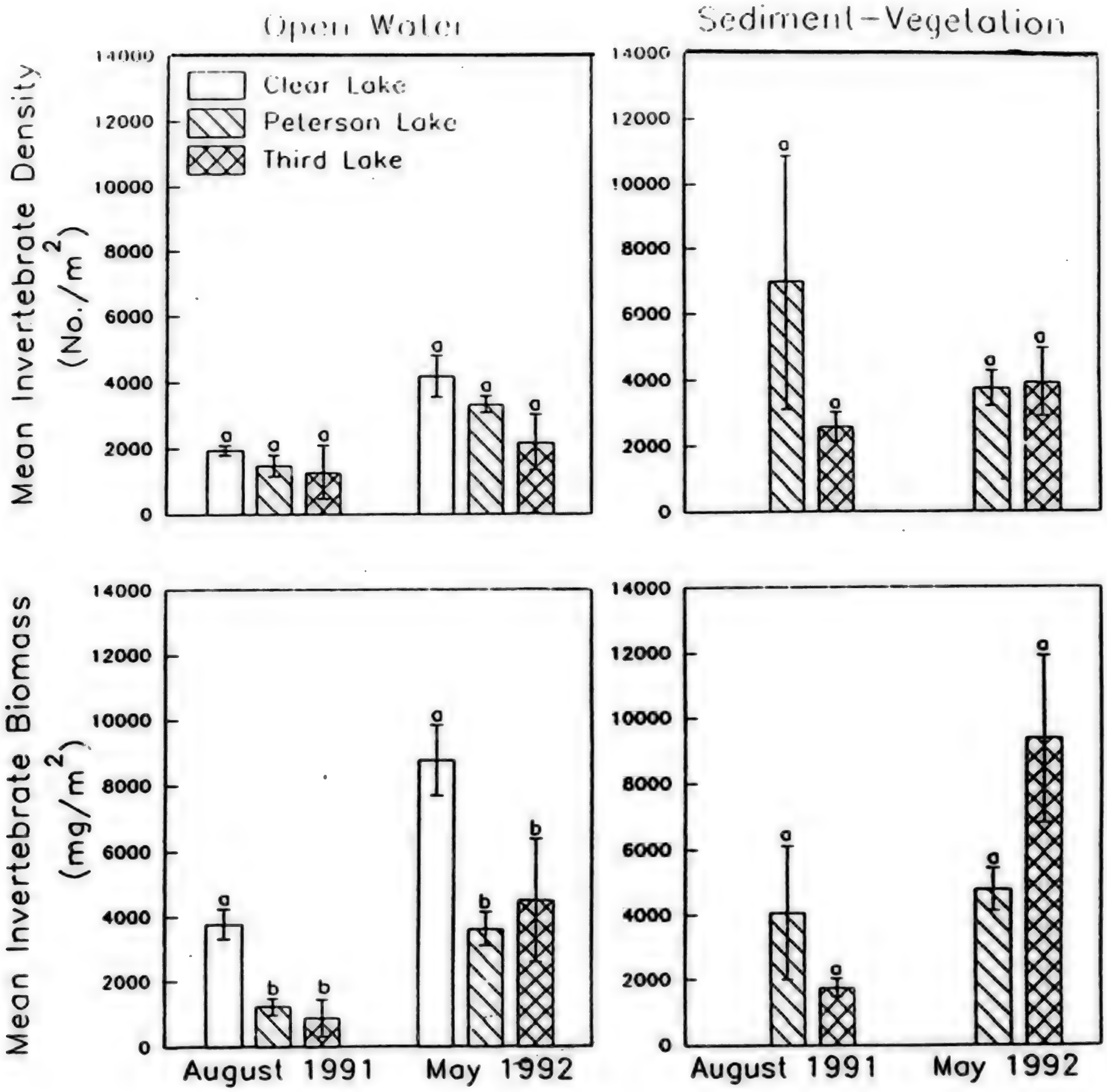

Figure 22. Mean invertebrate density and biomass (± 1 SE) in sediments in open water and in vegetative areas in Clear, Peterson, and Third Lakes, August 1991 and May 1992. Bars with different letters indicate significant differences (*P* ≤0.05) in density or biomass among lakes.

Seasonal Effects

Significant differences in invertebrate density between seasons were observed only in open water habitats in Peterson Lake ($P = 0.002$), where densities averaged 1,475 individuals/m^2 in August and 3,331 individuals/m^2 in May (Fig. 23). In open water habitats in Third Lake, the mean density of invertebrates ranged from 1,281 individuals/m^2 in August to 2,169 individuals/m^2 in May, although this increase was not statistically significant. There was no seasonal difference in density in invertebrates sampled from substrate beneath macrophyte beds in either Peterson or Third Lakes.

In contrast to density, significant differences in total biomass were observed between seasons for both open water and sediment-vegetation habitats in Peterson and Third Lakes. In each case, biomass was significantly greater in May than in August (Fig. 23).

Habitat Effects

Invertebrate density was significantly greater in sediment-vegetation habitats compared to in open water habitats in both Peterson ($P = 0.027$) and Third ($P = 0.035$) Lakes in August (Fig. 24). In May, invertebrate density was not significantly different between habitat types within a lake. However, mean densities increased from 3,331 individuals/m^2 in open water habitats to 3,730 individuals/m^2 in substrate beneath macrophyte beds in Peterson Lake and from 2,169 individuals/m^2 in open water habitats to 3,929 individuals/m^2 in substrate beneath macrophyte beds in Third Lake.

Total biomass was similar between habitat types within a lake in both seasons. A general trend of higher biomass in substrate beneath macrophyte beds compared to open water was apparent in both Peterson and Third Lakes in both August and May (Fig. 24). Biomass estimates from open water habitats in Clear Lake approached, and sometimes exceeded, biomass of invertebrates sampled from substrate beneath macrophyte beds in both Peterson and Third Lakes.

Species Composition

Overall, the invertebrate community in the Finger Lakes was dominated by five major groups: annelids, dipterans, amphipods, ephemeropterans, and coleopterans (Figs. 25 and 26). In Clear Lake, the invertebrate community was dominated by dipterans (*Tanypus stellatus* in August and *Procladius* spp. in May) and annelids (primarily Tubificidae without hair chaetae) in both August and May.

In Peterson Lake, dipterans and annelids comprised a large fraction of the total density and biomass in both August and May. However, the dipteran community changed from a dominance of *Polypedilum halterale* and *Procladius* spp. in August to a community dominated by Chironomus spp., *Dicrotendipes nervosus*, *Endochironomus* spp., and *Procladius* spp. in May. The amphipod *Hyalella azteca* contributed about 14% of the total density in August in substrates beneath macrophyte beds. Caenid mayflies comprised between 0% and 18% of the total biomass in Peterson Lake in August and between 12% and 19% of the biomass in May. Coleopterans were dominated by *Dubiraphia* spp. in both August and May.

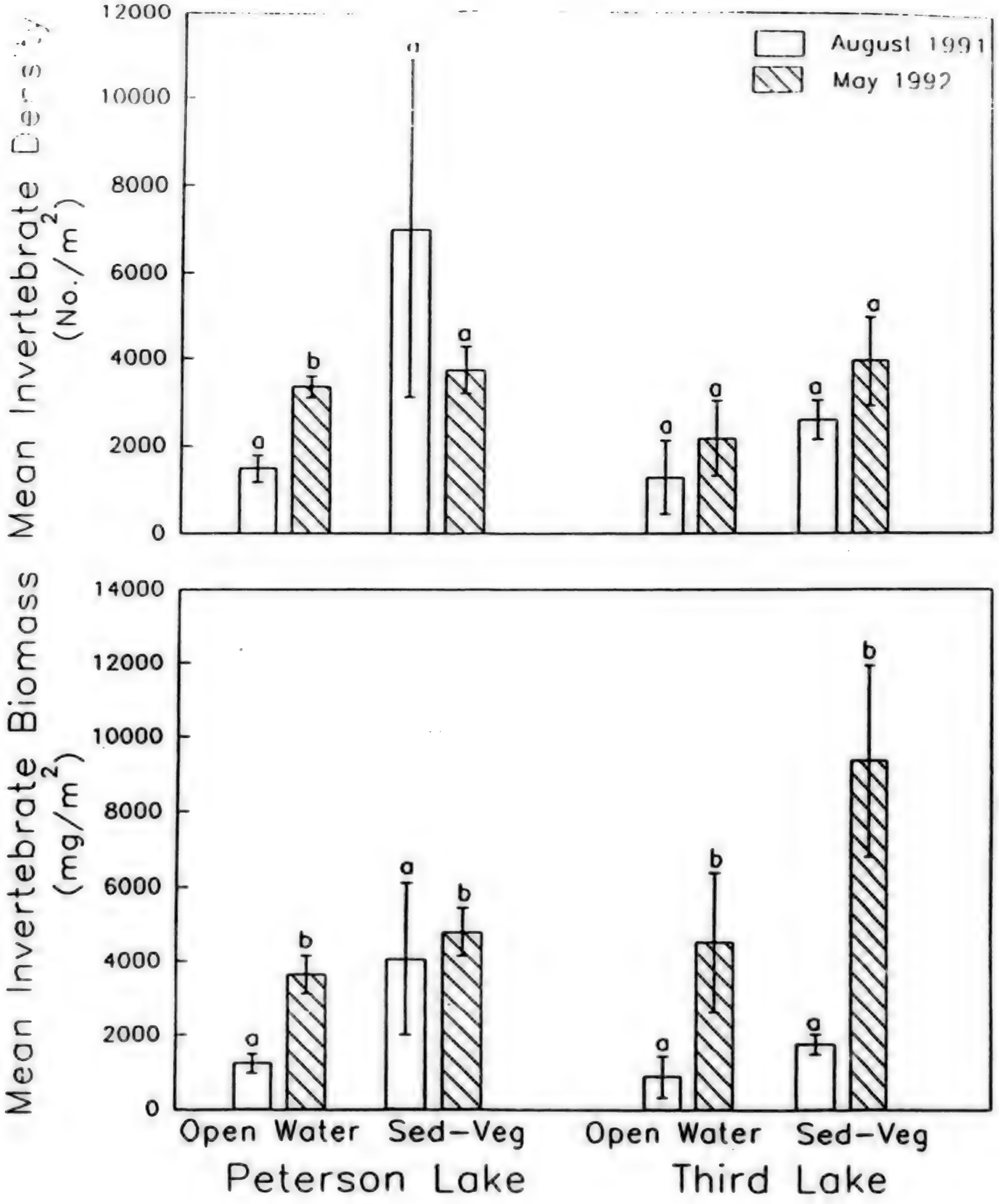

Figure 23. Comparison of mean invertebrate density and biomass (± 1 SE) over seasons in Peterson and Third Lakes. Invertebrates were sampled from sediments in open water and in vegetative areas. Bars with different letters indicate significant differences ($P \leq 0.05$) in density or biomass between seasons.

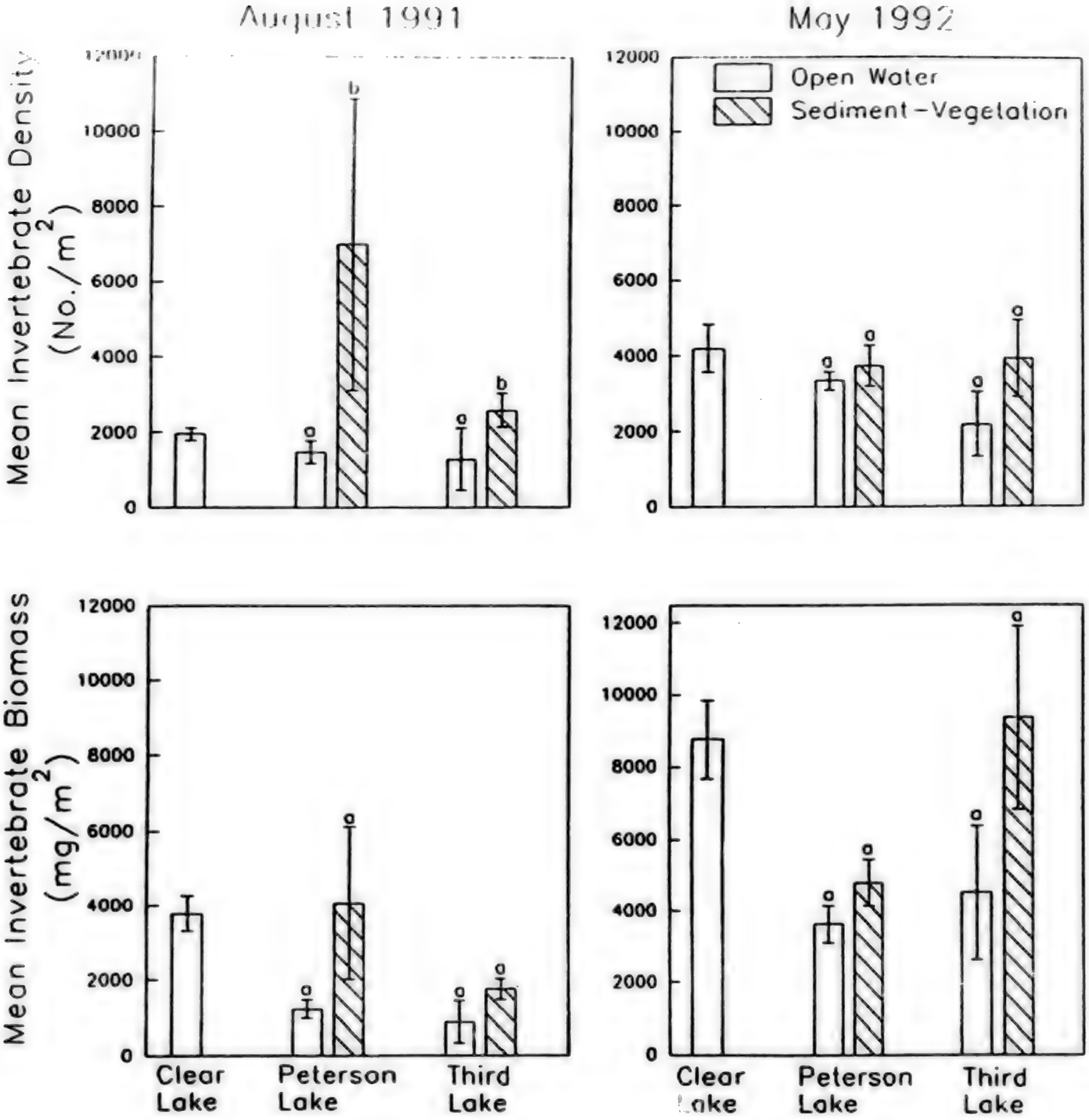

Figure 24. Comparison of mean density and biomass (± 1 SE) of invertebrates sampled in sediment in open water and in vegetative areas. Vegetative areas in Clear Lake were too sparse to sample. Bars with different letters indicate significant differences ($P \leq 0.05$) in density or biomass between habitat types.

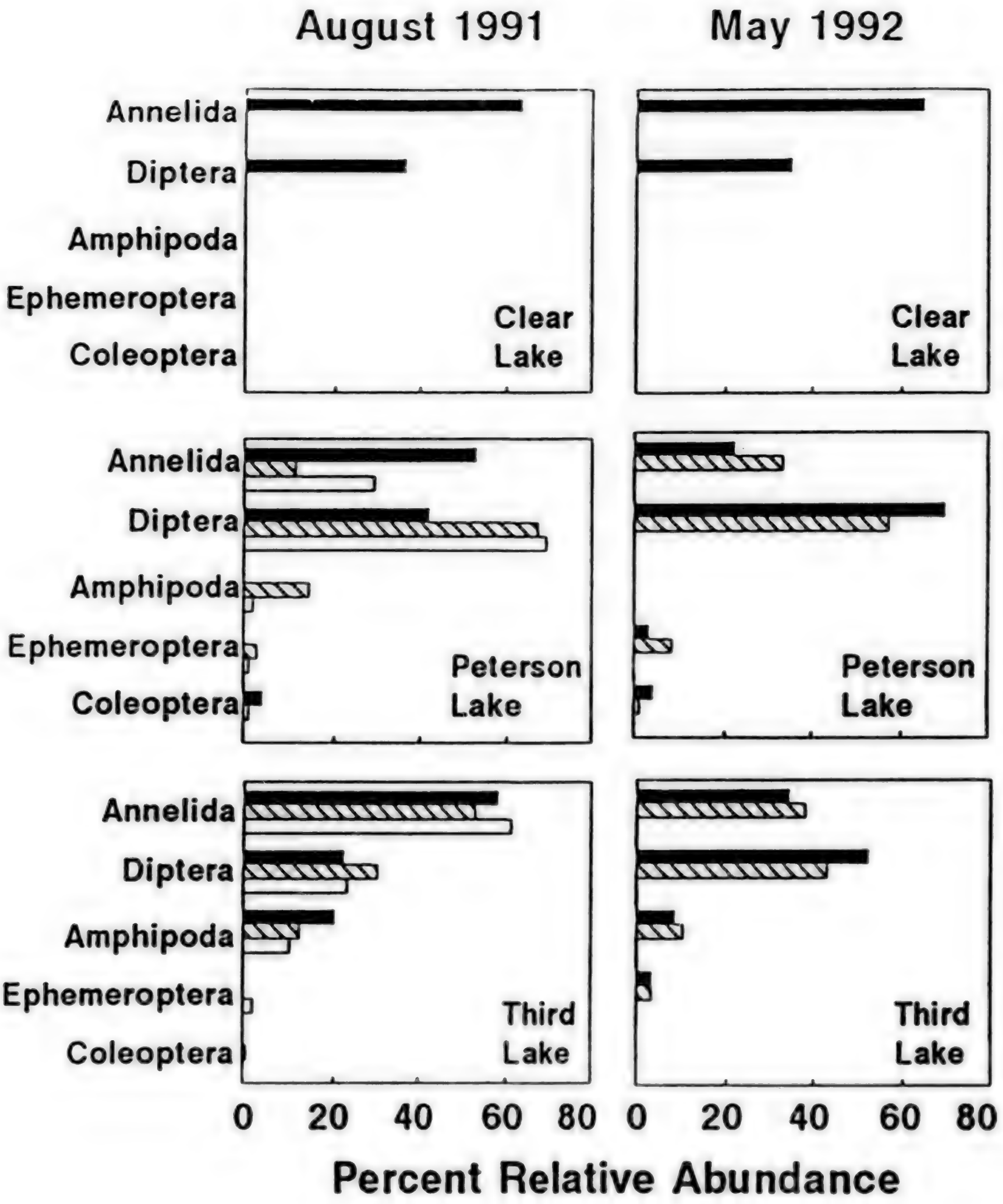

Figure 25. Seasonal changes in the percent numerical abundance of the five dominant invertebrate groups based on density in the Finger Lakes. Invertebrates were sampled from open water (solid bars), sediment beneath vegetation (hatched bars), and vegetation (open bars).

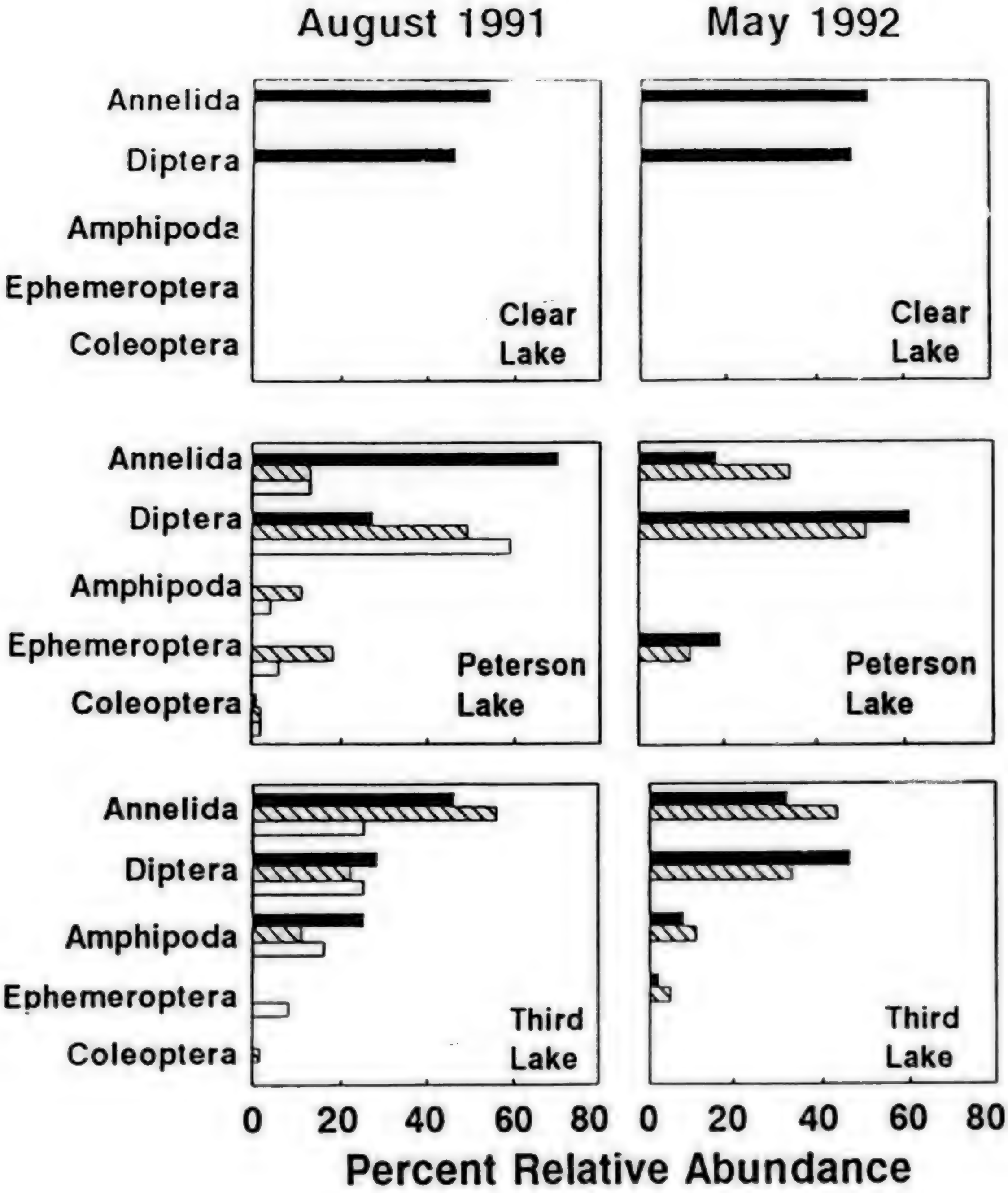

Figure 26. Seasonal changes in the percent numerical abundance of the five dominant invertebrate groups based on biomass in the Finger Lakes. Invertebrates were sampled from open water (solid bars), sediment beneath vegetation (hatched bars), and vegetation (open bars).

The invertebrate community in Third Lake was also dominated by dipterans and annelids in both seasons. The annelids were principally Tubificidae without hair chaetae and *Quistadrilus multisetosus*. The dipteran community changed from one dominated by *Dicrotendipes* spp, *Ablabesmyia* spp., and *Chironomus* spp. in August to a community dominated by *Endochironomus* spp., *Cladopelma* spp., and *Glyptodendipes* spp. in May. Mayflies were represented by *Caenis* spp. in August, and by *Caenis* spp. and *Siphlonurus* spp. in May. The coleopteran community was dominated by *Berosus* spp. in both seasons.

Species richness is defined here as Hill's (1973) diversity number N0, which represents the number of all species in a given sample regardless of their abundance (Ludwig and Reynolds 1988). Generally, species richness was greatest in the two habitats influenced by vegetation (Table 8). In Third Lake, the highest mean species richness value of 14.1 species was found in vegetative habitats, whereas in Peterson Lake, the highest mean species richness value of 15.8 species was found in substrate beneath vegetation. Open water habitats supported fewer invertebrate species than habitats influenced by vegetation (Table 8).

Hill's (1973) diversity number N1 is a measure of the number of abundant species in a sample and as such represents an interpretable diversity index that has the appeal of being reported in units of species numbers (Ludwig and Reynolds 1988). Generally, species diversity (N1) followed a similar trend as species richness, with the highest diversity in habitats influenced by vegetation.

Species evenness is the second component in diversity indices (species richness is the first) and refers to how the number of individuals are distributed among the species (Ludwig and Reynolds 1988). We used the modified Hill's ratio (E5) in which the evenness value approaches zero as one species becomes dominant. Evenness measures for invertebrates in open water habitats in Peterson and Third Lakes were markedly different between August and May (Table 8). In August, more species were equally abundant, whereas in May, fewer species were numerically dominant. All other habitats had similar evenness values.

Synopsis

Overall, the greatest changes in invertebrate density in the Finger Lakes occurred at the habitat level, while the greatest changes in total biomass were observed at the seasonal level. Clear Lake generally had a higher invertebrate density and greater biomass than either Peterson or Third Lakes. Density and biomass estimates in Peterson and Third Lakes were similar. For seasonal effects, density and biomass were generally lower in August than in May, probably due to emergence of adults. Density and biomass were greater in sedimentary substrate beneath macrophyte beds than in open water habitats. Macrophytes themselves generally supported the highest mean number of species.

The invertebrate community in the Finger Lakes was dominated by annelids, dipterans, amphipods, ephemeropterans, and coleopterans. The mean number of species varied from 6.2 in open water to 15.8 in substrate beneath macrophyte beds. Evenness values in the Finger Lakes approached zero (maximum value of 1.23), which suggests that few species dominated invertebrate abundance.

We have suggested that the Finger Lakes will become more similar as a result of flow alteration. Furthermore, the effects of flow alteration on benthic macroinvertebrates are predicted to be dependent on changes observed in the macrophyte community. Thus, it is difficult at this

Table 8. Hill's diversity numbers N0 and N1 as measures of species diversity and Modified Hill's Ratio (E5) as a measure of evenness in invertebrates from the Finger Lakes, expressed as mean ± 1 SE. N0 is the mean number of all species in the sample, regardless of abundance, and N1 is a measure of the mean number of abundant species in the sample.

Lake, habitat	August 1991 Species richness (N0)	August 1991 Species diversity (N1)	August 1991 Evenness (E5)	May 1992 Species richness (N0)	May 1992 Species diversity (N1)	May 1992 Evenness (E5)
Clear Lake						
Open water	6.9 ± 0.6	4.1 ± 0.4	0.74 ± 0.05	7.9 ± 0.9	4.0 ± 0.5	0.66 ± 0.07
Peterson Lake						
Open water	8.8 ± 1.0	5.8 ± 0.3	1.23 ± 0.43	12.9 ± 0.7	6.7 ± 0.5	0.64 ± 0.04
Sediment-vegetation	15.8 ± 2.3	7.7 ± 1.0	0.72 ± 0.08	14.9 ± 0.7	7.6 ± 0.6	0.66 ± 0.06
Vegetation	11.5 ± 2.6	5.1 ± 0.7	0.68 ± 0.06	---[a]	---[a]	---[a]
Third Lake						
Open water	6.2 ± 2.0	3.2 ± 0.7	1.22 ± 0.53	8.7 ± 2.4	4.5 ± 0.9	0.89 ± 0.17
Sediment-vegetation	10.5 ± 1.9	4.9 ± 0.8	0.57 ± 0.04	13.3 ± 2.8	6.6 ± 1.7	0.65 ± 0.08
Vegetation	14.1 ± 1.4	6.1 ± 0.9	0.59 ± 0.03	---[a]	---[a]	---[a]

[a] Vegetation not sampled in May 1992

time to predict whether changes occurring at the lake, habitat, or season level will be driving invertebrate density and biomass. However, if the lakes become more similar, we predict that species richness (N0) will remain unchanged, evenness will increase, and species diversity (N1) will increase because it is sensitive to changes in rare species.

Fish

An angler survey of the Finger Lakes was conducted by the Minnesota Department of Natural Resources from December 7, 1992, to March 12, 1993. Sampling was stratified by day type (weekdays and weekends/holidays) within each month, and 38 of the 96 possible days (40%) were sampled. Over this period, estimates were 466 angler-hours expended, with a harvest of 213 bluegills (*Lepomis macrochirus*) and 20 black crappies (*Pomoxis nigromaculatus*). Few other species were caught. Monthly effort was similar during December, January, and February. Third Lake accounted for about half the effort (236 angler-hours) and nearly all (99%) of the bluegill harvest. Angler harvest and effort were greatly reduced as compared to winter 1991-1992 (Finger Lakes Pre-Project Report Number 2, 1993). A radiotelemetry study conducted from December 8, 1992, to February 24, 1993, indicated that bluegill and largemouth bass (*Micropterus salmoides*) exhibit little diel movement in winter.

Flooding in spring 1993 was severe and extended into early fall, possibly making spring and fall fyke netting less efficient than in previous years. Fyke net catch-per-unit-effort (CPUE) for all species combined for spring and fall (Table 9) was less than half of that for 1992 (Barko et al. 1993). Although the number of species captured by fyke nets in 1993 (Table 9) was similar to in 1992, relative species composition differed between years. Spring catch in 1993 was dominated by black crappie, followed by freshwater drum (*Aplodinotus grunniens*), yellow perch (*Perca flavescens*), and bluegill. Fall catch was dominated by black crappie, followed by bluegill, yellow perch, and catostomids. Similar to in 1992, CPUE in 1993 increased in fall for most species and groups compared to in spring.

We calculated population estimates for bluegill, black crappie, and largemouth bass in spring (June 1-18) and fall (August 30-October 13) 1993 (Table 10). Fall estimates were primarily based on electrofishing, which was done when water levels had returned to normal in late fall. Distribution of bluegills and largemouth bass in fall 1993 was similar to in 1992, with bluegill concentrated in Third Lake and largemouth bass in Lower Peterson Lake. However, black crappie were concentrated in First Lake in 1993 instead of in Lower Peterson and Third Lakes as in 1992. In spring, we estimated populations for the entire system, but not for individual lakes, because extensive flooding made electrofishing inefficient and few fish were recaptured.

Overwinter mortality estimates were calculated based on population estimates from fall 1992 and spring 1993 (Table 10). However, because spring population estimates were based on a small number of recaptures, the accuracy of mortality estimates is questionable. Total overwinter mortality of bluegill was 30% which, based on the estimated winter harvest of 213 bluegills, can be apportioned as 1% harvest mortality and 29% natural mortality. Total overwinter mortality was 65% for black crappie and 26% for largemouth bass, with negligible harvest mortality for both species.

Stomach contents of juvenile and adult bluegill, black crappie, and largemouth bass collected in summer and fall 1993 (Table 11) were similar to those from 1992, except that zooplankton were more common in all groups except adult largemouth bass. Macroinvertebrates, primarily

Table 9. Catch per net-day of fish in fyke nets, and total number of species caught, total number of fish caught, and effort (net-days) for fyke netting in the Finger Lakes (all lakes combined) during spring (June 7-18) and fall (August 30-September 3) 1993

Taxa	Spring	Fall
Dorosoma cepedianum	<0.1	0.2
Esox lucius	<0.1	0.2
Cyprinus carpio	0.4	0.2
Catostomidae[a]	0.6	1.3
Morone chrysops	<0.1	0.1
Lepomis macrochirus	0.7	1.7
Other *Lepomis* spp.[b]	0.6	0.4
Pomoxis nigromaculatus	3.1	5.2
Pomoxis annularis	0.2	0.1
Perca flavescens	0.8	1.3
Aplodinotus grunniens	1.5	0.4
Other species[c]	0.7	0.3
Number of species	30	27
Number of fish caught	1,223	819
Number of net days	144	72
Total catch per net day	8.0	11.4

[a] Includes *Carpiodes carpio, C. cyprinus, Catostomus commersoni, Ictiobus bubalus, I. cyprinellus, Minytrema melanops, Moxostoma anisurum,* and *M. macrolepidotum*

[b] Includes *Lepomis cyanellus, L. gibbosus,* and *L. humilis*

[c] Includes *Lepisosteous osseus, L. platostomus, Amia calva, Notemigonus crysoleucas, Ameiurus melas, A. natalis, A. nebulosus, Ictalurus punctatus, Ambloplites rupestris, Stizostedion canadense,* and *S. vitreum*

Table 10. Population estimates and 95% confidence intervals (C.I.) for bluegills and black crappies exceeding 120 mm in total length and for largemouth bass exceeding 150 mm in total length in the Finger Lakes during spring and fall 1993. A dash (--) indicates that too few fish were recaptured to calculate a population estimate.

Lake	Black crappie		Bluegill		Largemouth bass	
	Population estimate	95% C.I.	Population estimate	95% C.I.	Population estimate	95% C.I.
Spring 1993						
Clear	856	445-1,801	1780	925-3,748	--	--
Peterson	--	--	--	--	--	--
Third	--	--	--	--	--	--
First	207	98-477	2,573	1,421-5,146	--	--
Schmoker's	--	--	--	--	--	--
Total system	3,154	2,083-5,017	15,831	10,231-25,709	849	401-1,958
Fall 1993						
Clear	549	285-1,156	2,485	2,041-3,025	249	194-319
Peterson	1,176	525-2,940	4,741	3,453-6,720	409	335-499
Third	732	327-1,830	19,368	13,639-28,482	145	75-304
First	3,597	1,927-7,357	1,435	1,116-1,841	166	106-274
Schmoker's	922	436-2,127	3,684	2,136-6,907	222	156-329
Total system	7,650	5,359-11,319	21,968	19,327-24,969	1,155	1,009-1,323

Table 11. Percent frequency occurrence of food items in the stomachs of juvenile (≤1 year) and adult (>1 year) fish, number of stomachs that were empty, and number that contained food, for bluegill, black crappie, and largemouth bass in the Finger Lakes. Data are combined from fish collected summer and fall 1993.

Food item	Bluegill		Black crappie		Largemouth bass	
	Age ≤1	Age >1	Age ≤1	Age >1	Age ≤1	Age >1
Zooplankton	61	58	72	12	26	0
Macroinvertebrates	92	97	71	69	79	31
Fish	0	0	3	49	23	79
Other[a]	57	79	57	15	20	15
Number of stomachs with food	138	152	58	74	101	48
Number of empty stomachs	26	14	12	11	38	52

[a] Plant material and unidentified organic matter

amphipodsand dipterans, were the most frequent food item in stomachs of all groups, except for juvenile black crappie, in which zooplankton were equally as frequent as macroinvertebrates, and adult largemouth bass, in which fish were most frequent. Fish were also common in the diets of juvenile largemouth bass and adult black crappie.

Scales collected in fall 1991 from bluegill, black crappie, and largemouth bass were used to determine capture length-at-age and back calculated length-at-age (Fig. 27 and Tables 12, 13, and 14). Aging of fish captured in spring 1992 through fall 1993 is currently under way to determine fish growth during that period.

Preliminary analysis of the seasonal movement (fall 1991 through fall 1993) of tagged fish in Finger Lakes indicates moderate interlake movement. In fall, largemouth bass tend to move into Lower Peterson Lake, while bluegill and black crappie move out of Lower Peterson and Schmoker's Lakes into Clear and Third Lakes (Fig. 28). In spring, all three species tend to disperse from Clear Lake into other lakes. Bluegill show strong movement into Third and Peterson Lakes, while largemouth bass show strong movement into Third Lake.

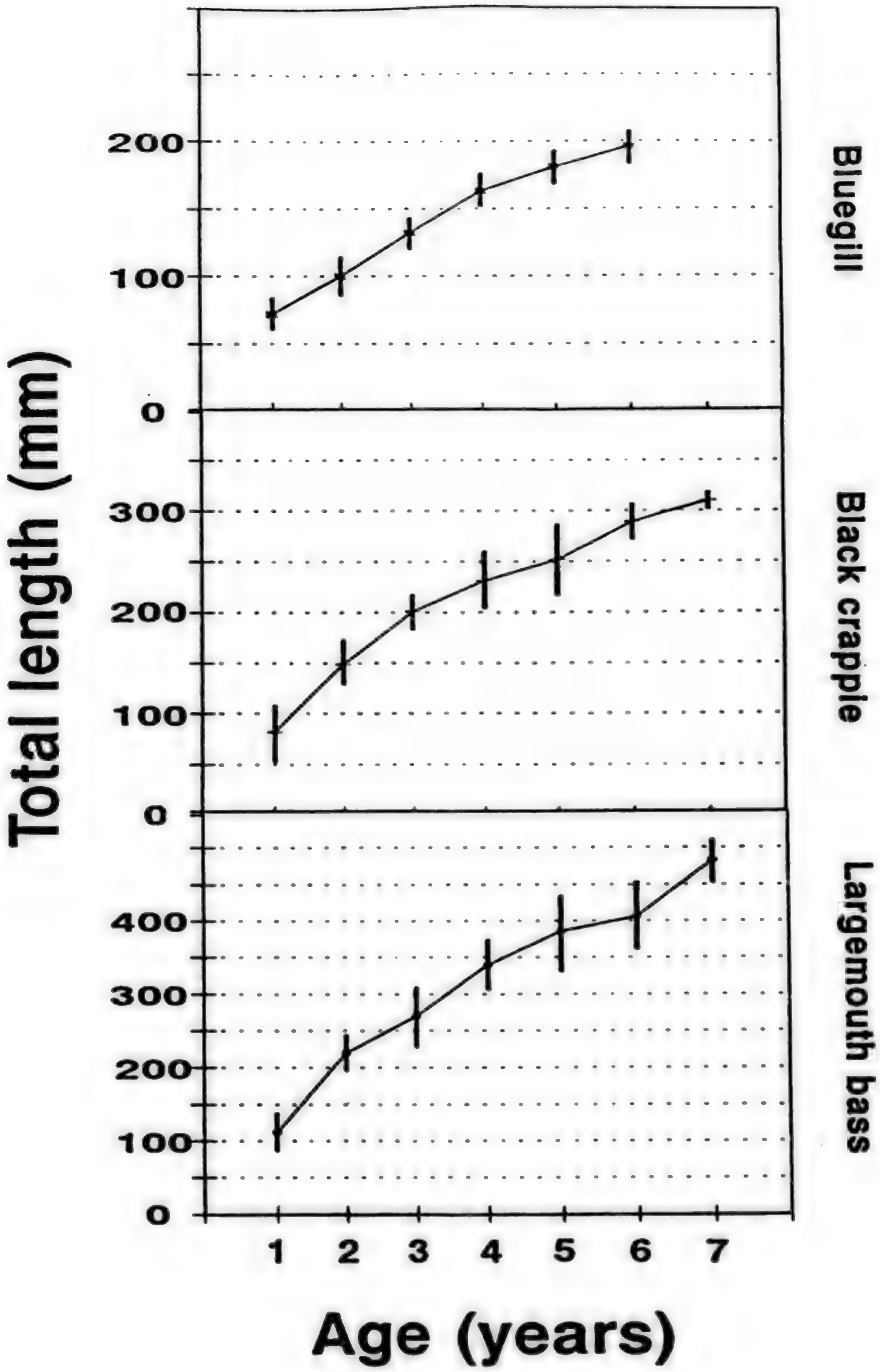

Figure 27. Capture length-at-age for bluegill, black crappie, and largemouth bass from fall 1991. Vertical bar is plus and minus one standard deviation.

Table 12. Bluegill length (mm) and standard deviation (SD) at age by cohort as determined by the University of Minnesota's computer program for analyzing growth of fish (Weisberg 1989). Rows are cohorts, columns are ages, and diagonals are years.

Cohort	Age -->	1	2	3	4	5	6
1	Average	64	--	--	--	--	--
	SD	4					
2	Average	62	101	--	--	--	--
	SD	4	6				
3	Average	60	98	133	--	--	--
	SD	4	5	7			
4	Average	60	95	129	162	--	--
	SD	4	5	7	8		
5	Average	62	96	128	160	182	--
	SD	4	6	7	8	8	
6	Average	57	93	124	156	175	194
	SD	7	8	9	9	10	14
	Column mean	61	97	129	159	179	194

Table 13. Black crappie length (mm) and standard deviation (SD) at age by cohort as determined by the University of Minnesota's computer program for analyzing growth of fish (Weisberg 1989). Rows are cohorts, columns are ages, and diagonals are years.

Cohort	Age -->	1	2	3	4	5	6	7
1	Average	85	--	--	--	--	--	--
	SD	7						
2	Average	82	151	--	--	--	--	--
	SD	6	8					
3	Average	77	143	194	--	--	--	--
	SD	6	8	10				
4	Average	75	137	184	231	--	--	--
	SD	6	8	10	11			
5	Average	71	131	174	217	256	--	--
	SD	6	8	10	11	12		
6	Average	80	136	177	215	251	288	--
	SD	7	9	10	12	13	15	
7	Average	67	132	168	205	236	270	309
	SD	9	10	12	13	14	17	20
	Column mean	77	138	179	217	248	279	309

Table 14. Largemouth bass length (mm) and standard deviation (SD) at age by cohort as determined by the University of Minnesota's computer program for analyzing growth of fish (Weisberg 1989). Rows are cohorts, columns are ages, and diagonals are years.

Cohort	Age -->	1	2	3	4	5	6	7
1	Average	115	--	--	--	--	--	--
	SD	7						
2	Average	108	212	--	--	--	--	--
	SD	7	10					
3	Average	109	206	283	--	--	--	--
	SD	7	10	12				
4	Average	106	204	274	341	--	--	--
	SD	7	10	12	14			
5	Average	105	200	271	331	384	--	--
	SD	7	10	12	14	15		
6	Average	106	200	267	329	375	409	--
	SD	8	12	13	15	16	19	
7	Average	101	196	262	320	368	395	469
	SD	13	16	18	19	20	22	28
	Column mean	107	203	271	330	376	402	469

Synopsis

Population estimates of target fishes were lower for spring 1993 as compared to population estimates for 1992. In part, this may be a result of inefficient sampling because of severe and extended flooding in 1993. Flooding also likely reduced the efficiency of both spring and fall fyke netting, resulting in reduced CPUE for most species in 1993. Fall 1993 population estimates of target fishes were similar to population estimates in fall 1992, indicating that spring population estimates may have been inaccurate and that population sizes of target fishes were similar between years. Diets of target fish were still primarily macroinvertebrate-based; however, stomachs from all groups showed an increase in the frequency of zooplankton. Analysis of the movement of tagged fishes confirmed that seasonal interlake movement is common and possibly related to food, reproductive, and overwintering requirements of these fishes.

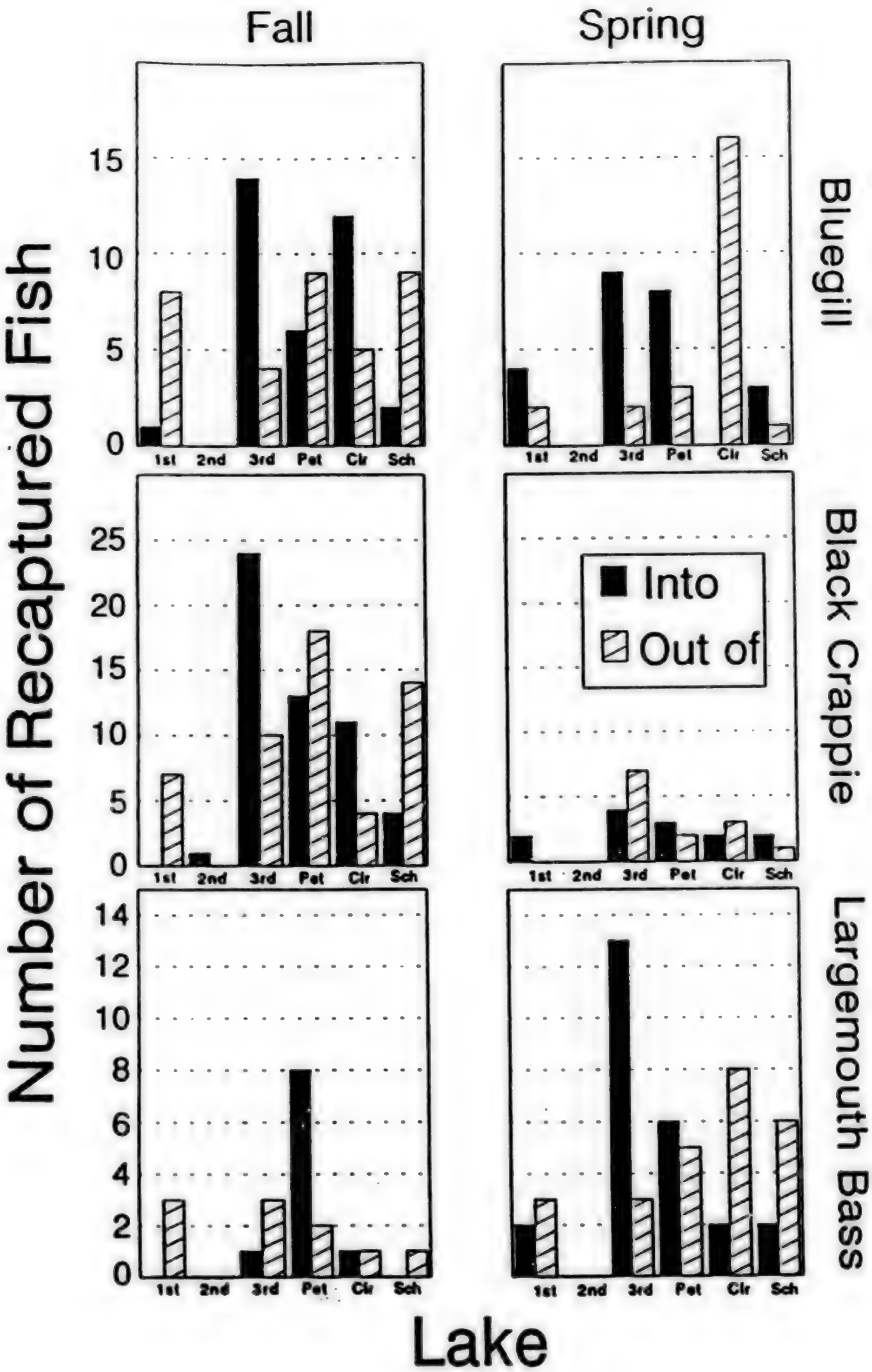

Figure 28. Spring and fall movement of tagged bluegills, black crappies, and largemouth bass in the Finger Lakes from fall 1991 through fall 1993. "Pet" is Lower Peterson Lake, "Clr" is Clear Lake, and "Sch" is Schmoker's Lake. "Into" is number of fish recaptured in that lake but tagged in another lake. "Out of" is the number of fish recaptured in another lake but tagged in that lake.

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13. ABSTRACT (Maximum 200 words)

The Finger Lakes Habitat Rehabilitation and Enhancement Project (HREP) is intended to improve winter habitat conditions for fish in a series of interconnected backwater lakes of the Mississippi River near Alma, Wisconsin. Winter habitat requirements (temperature, flow velocity, and dissolved oxygen) for the target fish population in the Finger Lakes have been defined and limnological efforts have been aimed at quantifying the spatial-temporal patterns and interrelationships among water movement, oxygen, and temperature. The progress to date (preconstruction) has included detailed investigations into (1) system hydrology (including dye-tracer studies), (2) oxygen supply and depletion, (3) temperature regime, (4) aquatic vegetation distribution, composition, and abundance, (5) macroinvertebrates, and (6) target fish species movements and food base. This report is the third in a series addressing preconstruction conditions. The report summarizes results of studies conducted during 1993.

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The Long Term Resource Monitoring Program (LTRMP) for the Upper Mississippi River System was authorized under the Water Resources Development Act of 1986 as an element of the Environmental Management Program. The mission of the LTRMP is to provide river managers with information to maintain the Upper Mississippi River System as a viable large river ecosystem given its multiple-use character. The LTRMP is a cooperative effort by the National Biological Survey, the U.S. Army Corps of Engineers, and the states of Illinois, Iowa, Minnesota, Missouri, and Wisconsin.

END

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